THE COUPLING OF PERCEPTION AND ACTION IN REPRESENTATION

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THE COUPLING OF PERCEPTION AND ACTION IN REPRESENTATION

by

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The coupling of perception and action in representation

ABSTRACT

This thesis examines how the objects that we visually perceive in the world are coupled to the actions that we make towards them. For example, a whole hand grasp might be coupled with an object like an apple, but not with an object like a pea. It has been claimed that the coupling of what we see and what we do is not simply associative, but is fundamental to the way the brain represents visual objects. More than association, it is thought that when an object is seen (even if there is no intention to interact with it), there is a partial and automatic activation of the networks in the brain that plan actions (such as reaches and grasps). The central aim of this thesis was to investigate how specific these partial action plans might be, and how specific the properties of objects that automatically activate them might be. In acknowledging that perception and action are dynamically intertwining processes (such that in catching a butterfly the eye and the hand cooperate with a fluid and seamless efficiency), it was supposed that these couplings of perception and action in the brain might be loosely constrained. That is, they should not be rigidly prescribed (such that a highly specific action is always and only coupled with a specific object property) but they should instead involve fairly general components of actions that can adapt to different situations. The experimental work examined the automatic coupling of simplistic left and right actions (e.g. key presses) to pictures of oriented objects. Typically a picture of an object was shown and the viewer responded as fast as possible to some object property that was not associated with action (such as its colour). Of interest was how the performance of these left or right responses related to the task irrelevant left or right orientation of the object. The coupling of a particular response to a particular orientation could be demonstrated by the response performance (speed and accuracy). The more tightly coupled a response was to a particular object orientation, the faster and more accurate it was. The results supported the idea of loosely constrained action plans. Thus it appeared that a range of different actions (even foot responses) could be coupled with an object's orientation. These actions were coupled by default to an object's X-Z orientation (e.g. orientation in the depth plane). In further reflecting a loosely constrained perception-action mechanism, these couplings were shown to change in different situations (e.g. when the object moved towards the viewer, or when a key press made the object move in a predictable way). It was concluded that the kinds of components of actions that are automatically activated when viewing an object are not very detailed or fixed, but are initially quite general and can change and become more specific when circumstances demand it.

TABLE OF CONTENTS

LIST OF BOXES

LIST OF TABLES

LIST OF TABLES (CONT)

LIST OF FIGURES

LIST OF FIGURES (CONT)

Declaration

I hereby certify that the work described in this thesis is my own, except where otherwise acknowledged, and has not been submitted previously for a degree at this or any other university.

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Publications

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Signed E M Symes

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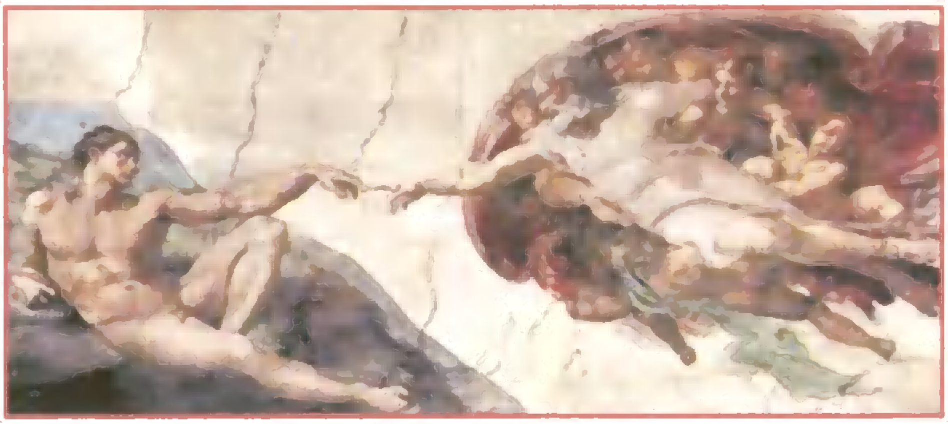
For Joseph and Tubbs

1. Introduction



Contents

1.1 Background and thesis overview

If you were asked to describe an apple that you were looking at, the nature of your descriptions would be dependent on the context of the description required. Compare for example, a general-purpose description of the apple with a description relative to what you could do with the apple. Each description might share similar dimensions, yet the properties of those dimensions might well be quite different (see Table 1.1).

Table 1.1 Context-dependent descriptions of an apple

Dimensions	General-purpose description	Action-oriented description
Identity	Apple	Edible fruit
Location	Centrally placed	Reachable distance
Shape	Roundish	Graspable with whole hand
Texture	Smooth	Smooth to hold, hard to bite
Volume	Approximately 350 cm^3	Fits in hand easily but not in mouth
Weight	Approximately 150 g	Light enough to lift easily
Colour	Reddish-green	Ripe for eating

Researchers interested in visual perception have arrived at analogously different context-dependent descriptions of visual processes. For those who asked, "How does vision derive useful general-purpose descriptions of the world?" answers came in the form of an abstract computational language of 'representations' (e.g. Marr, 1980, 1982). For those who asked, "How does vision enable an animal to act effectively in its environment?" answers came in the form of an ecological language of 'direct perception' that crossed the conceptual boundary between animal and environment (e.g. Gibson, 1979).

This thesis is concerned with exploring an increasingly popular middle ground, which asks the question, "How does vision derive action-oriented descriptions of the world that enable an animal to act effectively in its environment?" and answers it in the form of a computational language of representations that is not abstract, but based on the sensorimotor activity of the perceiver relative to aspects of the visual world. The central hypothesis under investigation, developed by Tucker and Ellis (e.g. Tucker, 1997; Tucker

& Ellis, 1998, 2001; Ellis & Tucker, 2000) states that simply looking at an object, regardless of any intention to act upon it, partially activates (i.e. below threshold) motor codes (i.e. spatio-temporal patterns of neuronal activity in the motor areas of the brain) that are related to components of the actions associated with that object. These motor codes form part of the overall visual representation of that object. For example, in addition to the various visual properties of the apple that are coded when looking at an apple (e.g. location, colour, size, texture etc.), there is also simultaneous coding of components of actions. Thus visual indicators of the volume of an object might be relevant to components of a specific grasp type, or the location of the object might be relevant to components of a reach with a particular hand. An associative mechanism is proposed that temporally integrates these perceptual and motor codes; the result of which is a coding that is neither visual, nor motor, but rather, visuomotor. It is thought that during a history of species and individual development these visuomotor codes come to represent visual objects. This hypothesis, an ecologically inspired computational approach to visual perception, will be referred to as the Action Potentiation Hypothesis (APH).

The general aim of this thesis is to expand the APH (both theoretically and in terms of new data), by drawing upon insights from a variety of large-scale theories of mind that unify perception, action and cognition within the context of an embodied activity. This chapter introduces computational and ecological approaches to vision, and critiques the notion of mental representation. Chapter 2 examines contemporary theories of 'embodied cognition' that seek a principled integration of mental capacities by emphasising the role of the action system. Chapter 3 assimilates these ideas with the APH and identifies some theoretical ambiguities that are addressed in the experimental objectives. These objectives, which are tested in Chapters 3-6, centre on the specificity of the APH, both in terms of action and visual object attributes. Chapter 7 summarises and discusses the experimental findings with respect to theory and research implications.

1.2 Two approaches to visual perception and its relation to action

This section introduces computational and ecological approaches to visual perception (and more generally, cognition). The following briefly introduces two broad camps of cognitive theories within which these approaches fall. Computational approaches are inherently representational, and as such assume that perception and cognition involve the processing of internally represented information (see 'theories of structure' below). Ecological theories however do not invoke representations or computations in perception and cognition, and as such are amenable to dynamical explanations that can cross the boundaries of brains, bodies and environment (see 'theories of change' below).

Theories of structure (classical)

Classical theories use the digital computer as a metaphor for the brain, thus mental processes are computational, serial and symbolic. Mental representations are assumed to be abstract symbolic structures that correspond to real physical structures in the brain (hence Newell's 1980, *physical* symbol systems). The combinatorial structure (syntactical and semantic) of these representations is assumed to correspond to structural relations among physical properties of the brain (Fodor & Pylyshyn, 1988).

Theories of structure (connectionist)

Connectionists model the information processing content of brain states using physiologically inspired artificial neural networks (ANNs). Connectionist architecture requires only causal connectedness as the primitive relation among content-bearing units (Fodor & Pylyshyn, 1988), and its internal structure is typically described in terms of local, featural or distributed representations (Franklin, 1995). In local representations, the state of a single unit corresponds to an item (e.g. a concept or object). In featural representations, patterns of activity over several units correspond to (or 'encode') individual items, and individual units correspond to features of the given item (each feature can participate in the representation of several different items). In distributed representations the pattern of activity over several units corresponds to an item (and each unit can participate in the representation of several different items). Taken as a whole, ANN's can be characterised as algorithmic processing machines (Bridgeman, 1998) whose representations consist of a correlational correspondence between properties of the world and the emergence of a global network state (Varela, Thompson & Rosch, 1991).

Theories of change (dynamic)

Dynamical theories model the changing behaviour of the brain during state transitions. Change is typically described as 'dynamic', and the intrinsic temporality of cognition is considered fundamentally important. Cognitive acts unfold in time, whereas representationalism (especially of the symbolic kind) is atemporal (Shanon, 1998; Smithers, 1998). Thus, at the extreme interpretation of the Dynamical Hypothesis formulated by van Gelder (1998), the notions of computation and representation are rejected. Instead it views cognitive agents as *instantiations* of dynamical systems (the 'nature hypothesis'), whose cognitive processes are best *understood* as dynamical systems (the 'knowledge' hypothesis). Consequently, van Gelder's (1995) preferred metaphor for cognition is the standard example of a dynamical system, the Watt steam governor (see Figure 1.1).

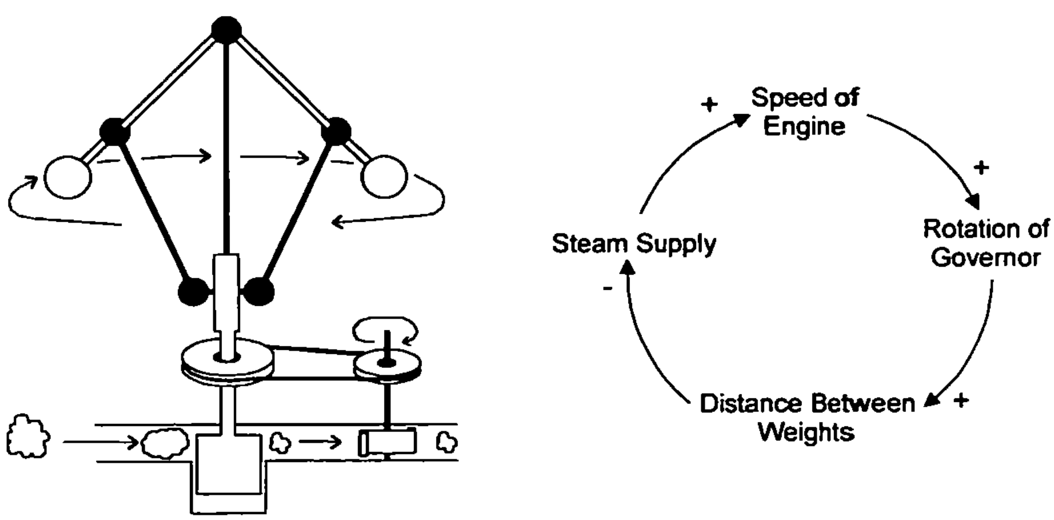


Figure 1.1 An illustration of a centrifugal governor and its feedback loop (adapted from Capra, 1996). Steam drives an engine connected to a flywheel that turns a spindle with two weights attached to arms. As the engine speed increases the spindle rotates faster, increasing centrifugal force, which moves the weights further apart, thus raising the piston and cutting off the steam supply. This reduced supply slows the engine down, which slows the spindle and reduces centrifugal force such that the weights move closer together, thus lowering the piston and increasing the steam supply. The governor therefore works as a self-regulating or negative feedback loop.

Theoretical debates

Classical theories adhere to the functionalist doctrine of the Physical Symbol System Hypothesis whereas connectionists agree with Searle (1980) that mental hardware matters. As most ANN's are digital simulations they do not fully escape the spectre of functionalism, and furthermore connectionist representations often appear to have more in common with classical symbolism than with real brain states (Smolensky, 1988). Indeed, Fodor & Pylyshyn (1988) argued that connectionism is merely a theory of how cognition is neurally implemented, and as such is not incompatible with classical information-processing approaches. The debate runs deep, but on the whole the digital computer metaphor for the brain has been rejected and many commentators champion connectionist over classical theories (e.g. Clark, 1997; Franklin, 1995; Varela, Thompson & Rosch, 1991).

While the details of a more recent debate between theories of structure and change are beyond the scope of this introduction, it is worth speculating that a) connectionist models are themselves special kinds of dynamical models, as stated by Smolensky's, (1988) 'connectionist dynamical system hypothesis'; b) whether cognition is best modelled algorithmically (using Boolean algebra) or dynamically (using systems of differential equations) may turn out to be a pragmatic decision (Bridgeman, 1998; Keijzer, Ben and van der Heijden, 1998); c) connectionist and dynamical theories share much common ground in their reasons for rejecting the digital computer metaphor for the brain; d) a theory is needed that incorporates both structure and change (Mitchell, 1998); and d) due consideration to the temporality of cognition may be essential, thus representations must be seen as dynamic.

1.2.1 Computational approaches

Visual Perception

In keeping with classical theories of structure (although more recently there have been connectionist implementations inspired by his work), Marr (1982) suggested that the purpose of the visual system is to derive useful descriptions (representations) of the world that can then be accessed and used by other systems (such as the action system). Marr's computational approach closely resembles the three tenets of a caricature of 'pure vision' identified by Churchland, Ramachandran & Sejnowski (1994):

1) *The visual world:* It is assumed that the goal of vision is to create a detailed model of the visual world in the brain. The process of forming visual representations is taken to be one of scene recovery, so effective, that what we see is a 'fully elaborated' representation that corresponds to the visual scene.
2) *Hierarchical processing:* The construction of representations is assumed to follow a distinct processing order. Early stages of retinal processing lead to the lateral geniculate nucleus and then on to various higher cortical stages. As processing advances through successive stages, more and more specific features are extracted from the earlier retinal stages until integration of highly specified features results in the 'fully elaborated representation'.
3) *Dependency relations:* It is further assumed that in general, higher levels of processing (e.g. problems such as segmentation and pattern recognition) depend on lower levels of processing (such as determining edges, or detecting motion), but not vice-versa.

Churchland et al. go on to convincingly challenge all of these tenets, suggesting that vision is better described as an active, explorative process that interacts with other sensory modalities, top-down cognitive influences and the sensorimotor system that controls the visual system (in particular exploratory eye, head and body movements that can greatly reduce the computational problems of vision). This 'interactive' account of vision that moves away from treating representations as essentially passive, picture-perfect 'snapshots' of the outside world, echoes the criticisms of Gibson (1979) made over two decades ago. There is considerable recent support for this view (e.g. Brooks, 1991; Clark, 1997; Ballard, 1991; O' Regan & Levy-Schoen, 1983; O'Regan & Nöe, 2001), which will receive further attention in section 1.3.

For present purposes however, it will simply be noted that the caricature of 'pure' vision rests on assumptions of predominantly linear stages of information processing between hierarchically arranged modular systems. Within any particular stage, there may however be parallel processing between heterarchically arranged modular subsystems. The end result of visual processing is an elaborate representation of a visual scene, the format of which is abstract enough to serve as a general-purpose description that is compatible with other, predominantly later, information-processing stages. Consequently, Marr's account of vision fits seamlessly within the human information-processing tradition, which assumes broadly distinct linear stages that are typified by the frequent use of box and arrow flow charts (see below for examples).

Information-processing

The conventions of the information-processing tradition are similarly stage-like, and three distinct processing stages are readily identifiable. Essentially, information is encoded, various operations transform this information into motor commands, and these commands are executed:

1) *The input stage:* a perceptual stage whereby sensory information is passively received and processed (for example the construction of a Marrian visual representation would occupy this stage of processing). Perceptual processing is passive in the sense that no other systems (e.g. the cognitive or action systems) are involved. The process is therefore predominantly bottom-up, allowing what is 'out-there' to be accurately perceived with little or no modulation by cognitive processes.
2) *The translation stage:* a cognitive stage whereby cognitive processes translate and mediate the perceptually derived information in terms of goal-generated commands, ready for use by the action systems.
3) *The output stage:* an intentional action stage whereby motor commands are carried out on the basis of the cognitive output of the previous translation stage.

In terms of these three processing stages, consider as an example the task of reaching towards and picking up an apple.

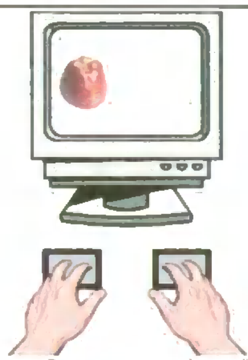
1) *The input stage:* Visual information about the apple is derived by the visual system.
2) *The translation stage:* A goal is formulated (e.g. pick up the apple), and relevant information derived at the input stage (e.g. the size, shape and location of the apple) is translated into various parameters that serve as action plans.
3) *The output stage:* These plans are then converted into specific muscle commands that are executed.

As with the caricature of 'pure vision', similar assumptions are made concerning the dependency relations of information processing stages. In order to operate, the output stage is dependent on the completion of processing at the input stage.

Two simple models of linear stage information processing

Consider also a hypothetical experimental abstraction of a rule-determined reach towards an apple. Participants sit in front of a monitor, and over several trials they are required to respond with left or right key presses to photographs of apples (the key press can be considered analogous to the initiation of a reach movement towards the apple). Participants are given a rule that arbitrarily maps a stimulus dimension (e.g. colour) onto a response dimension (e.g. response location). For example, participants may be required to press a key located on the left (with their left hand) when the apple is red, and press a key located on the right (with their right hand) when the apple is green. Although irrelevant to performing the task itself (which is defined by apple colour), sometimes the apple is located on the left side of the screen, and sometimes it is located on the right side of the screen. Thus, experimentally at least, there are three distinct stages (see Table 1.2).

Table 1.2 Experimental stages in hypothetical 'apple experiment'

Stage	Description	Example trial set-up
1	Stimulus presentation:	
	E.g. a left located red apple.	
2	Response determination:	
	E.g. in accordance with the mapping rule, identify the colour (e.g. red) and determine the appropriate response (e.g. left).	
3	Response execution:	
	E.g. press the left key.	

Results typical of an experimental set-up such as this would reveal key presses that are considerably faster and more accurate (in that fewer incorrect key presses are made), when the task *irrelevant* location of the stimulus (e.g. an apple on the *left*) is the same side as the task *relevant* location of the response (e.g. a *left* key press). These results demonstrate the 'Simon Effect' (first discovered by Simon and Rudell, 1967).

The Simon effect is usually classified as a case of stimulus-response-compatibility (S-R-C). This shares some similarities with the Stroop effect[1], which is usually classified as a case of stimulus-stimulus-congruence (S-S-C). The design of the 'apple experiment' described above adopts the methodology of the S-R-C paradigm, where there is typically a stimulus set, a response set and a mapping rule.

1) *The stimulus set:* contains stimuli with various dimensions (e.g. colour, size, identity, shape, location) some of which may have properties that vary across trials (e.g. left location, right location). Unlike the 'apple experiment', typically stimuli are abstract in nature (such as coloured two dimensional symbols or shapes).

2) *The response set:* contains responses with various dimensions (e.g. effector type, location), some of which may have properties that vary across trials (e.g. left location, right location). Responses are typically binary verbal responses (e.g. "Yes", "No"), or binary key-presses made with hands, feet or specific digits.

[1] The Stroop effect (Stroop, 1935, or see MacLeod, 1991 for a comprehensive review) reveals interference effects of incongruent stimulus properties. For example, the naming of ink colour is slow when the colour word is incongruent with the ink colour it is written in (e.g. the word 'red', written in green ink).

3) *The relationship between stimuli and responses:* Sometimes one or more stimulus dimensions can be 'compatible' with one or more response dimensions (e.g. a stimulus location can be compatible with a response location), or in S-S-C, two or more stimulus dimensions can be 'congruent' with each other (e.g. a colour can be congruent with the name of a colour). When there is S-R-C or S-S-C, task performance is robustly and reliably facilitated (e.g. fast reaction times and few mistakes). These effects are not specific to any modality, and can arise when the source of compatibility or congruence is relevant to performing the task, or when it is irrelevant. In terms of theoretical interpretation, the task is not usually treated as an abstraction of a real-life event (such as reaching towards an apple), but is treated at face value as an abstract task (see section 1.2.2. for an alternative view).

4) *The mapping rule:* is an instruction given to the participant that determines which property of a dimension of a response (e.g. dimension = location, property = left) is to be paired with which property of a dimension of a stimulus (e.g. dimension = colour, property = red). The precise phrasing of a mapping rule can influence the goal a participant formulates (which may refer to the anticipated outcome of a response, or to the response itself) and this can be crucial to the size and direction of any effects (e.g. Hommel, 1993).

The following describes two information-processing accounts of the Simon Effect. Although both reach different conclusions, it is notable that they both share a commitment to distinct linear stages of processing that support the three stages of input, transformation and output (presented earlier in the discussion of information-processing). Furthermore, in accord with tenets 2 & 3 of the caricature of 'pure' vision discussed earlier, they are both hierarchically organised with dependency relations that demand the completion of stimulus (input) processing before response (output) processing.

Hasbroucq and Guiard's (1991) three-stage model

Hasbroucq and Guiard (1991) argued that the Simon Effect is correctly classified as an S-S-C effect, caused by interference within the stimulus-encoding stage (stage 1 in Figure 1.2). They argued that although the relevant stimulus dimension (e.g. colour) may not itself have a spatial property, because the mapping rule assigns it to a spatial response, the colour dimension acquires a spatial connotation at the stimulus-encoding stage. Thus in the 'apple experiment', the assignment of the colour red to a left response, would result in 'red' acquiring a spatial code 'left'. When the 'left' (red) code coincides with a 'right' (right apple location) code, there is stimulus-stimulus incongruence, and poor performance would be taken to indicate processing interference between these incongruent codes.

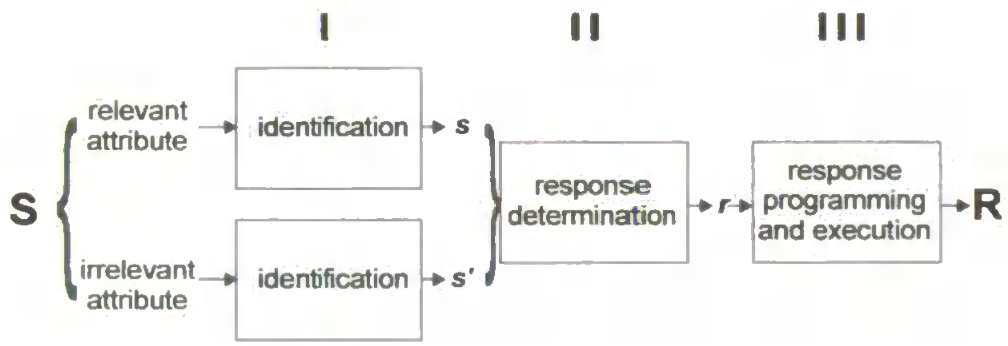


Figure 1.2 Three stages of information processing in a Simon or Stroop task (from Hasbroucq and Guiard, 1991, p.263, with shaded sections added) "This model assumes that at the stage of S identification both attributes of the S are identified in parallel [and automatically, for the irrelevant one], which leads to the production of two mental symbols s and s' that either agree or conflict with each other. The brace symbolizes an exclusive or relationship: The Simon or Stroop interference effect is assumed to end before the R-determination stage starts."

Kornblum, Hasbroucq and Osman's (1990) Dimensional overlap model

Models such as the 'Dimensional overlap (DO) model' (Kornblum *et al.*, 1990), attempt to explain a wide range of S-R-C effects in terms of a common, basic cognitive mechanism, whereas others such as the 'Dual Process (DP) model' (de Jong, Liang & Lauber, 1994) argue that many different mechanisms are involved, particularly within a range of spatial S-R-C tasks. Both however share the idea of dual processes (e.g. DO: automatic and rule/search-based, or DP: unconditionally automatic and conditionally automatic). In the DO model, the Simon Effect is classified as an S-R-C effect facilitated by the compatibility of two properties whose dimensions overlap. Specifically, facilitation occurs when the property of an irrelevant stimulus dimension (e.g. the left property of the left-right location dimension of an apple) is compatible with the property of a relevant response dimension (e.g. the left property of the left-right dimension of a key press). See Figure 1.3 for the major information-processing operations assumed by the DO model.

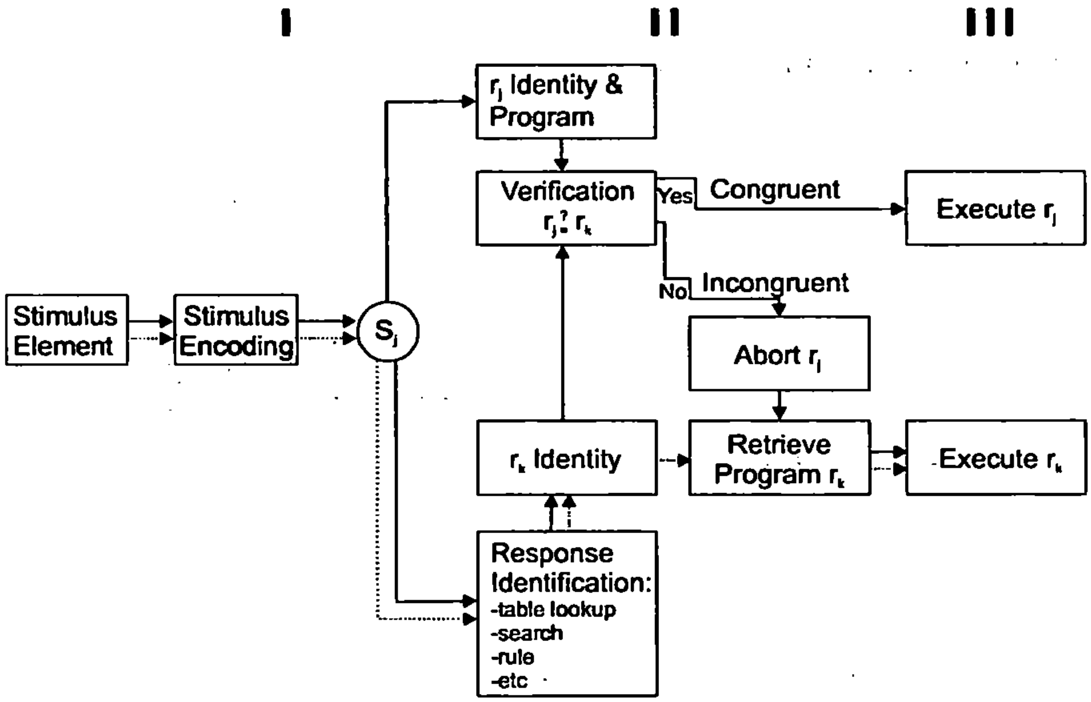


Figure 1.3 Three broad stages of information-processing operations identifiable in DO model of S-R-C tasks (adapted from Kornblum et al., 1990). Solid lines illustrate DO and dotted lines illustrate no DO. The uppermost shaded sections illustrate the operations involved in the automatic activation of the congruent response for S-R ensembles with DO. The lower shaded sections of the solid path illustrates the operations involved in the identification of the correct response.

The translation metaphor is adopted that is central to linear stage information-processing theories. Stimulus processing stages come first and response execution stages come last, with a translation stage bridging the gap between the two. Processing within stages is assumed to be automatic, in that any recoding or transformations are preset and occur immediately (and are not subject to interference or intervention from monitoring or controlling processes). Processing between stages is also assumed to be automatic, in that the output from any one stage is directly transmitted to and directly received by a subsequent stage, again without interference or intervention.

Kornblum, Stevens, Requin & Whipple (1999), describe the DO model (and their DO'97 model) as having two distinct sequential stages of processing, namely stimulus processing and response production. Nevertheless, three distinct stages can be identified within the model that correspond to the standard input -> translation -> output sequence discussed earlier (illustrated by the three shaded columns in Fig. 1.3). This can be described with reference to the 'apple experiment':

1) *The stimulus encoding stage:* visual properties of the apple such as its colour and location are encoded.
2) *The translation stage:* Two translation processes operate in parallel-
   a. *The representational component of the model:* If (and only if) there is DO between an irrelevant stimulus dimension (such as left apple location) and a relevant response dimension (such as left key press), an activating function automatically activates a response code, which will be referred to as the primed response code (e.g. a 'left' response code). Because of the automaticity of the activating process, it is assumed that it is completed before the confirmation process.
   b. *The processing component of the model:* Stimulus codes are compared to response codes via a confirmation function. The correct response is identified by a rule (if there is DO then a rule can be used which is fast) or a search (if there is no DO then a search is performed through a look-up table of S-R pairs, which is inherently slow). By identifying the correct response code, the primed response code is verified as valid or invalid. Where valid, (i.e. when the primed response code matches the correct response code) the primed response code is transmitted to the next stage (with no need for modification). Where invalid, (i.e. the primed response code does not match the correct response code) then the activated primed response code is aborted or modified and the correct response code is retrieved, programmed and then transmitted to the next stage.
3) *The response execution stage:* Depending upon the outcome of the confirmation function, either the primed response code or the correct response code transmitted from the previous stage (e.g. a 'left' response code) is directly received and immediately executed (as a left key press).

The assumption of strict separation of the stage sequence has been relaxed in recent years by models of parallel and distributed processing. Indeed Kornblum *et al.* (1999) have produced just such a connectionist model called DO'97. How the DO'97 model essentially differs from its predecessors (including Kornblum & Lee's, 1995 DO model that incorporates S-S-C tasks) is that independence between stages is no longer assumed, thus allowing for temporal overlap. Importantly however, the dependency relations between stimulus and response stages still hold for DO'97. There are two distinct layers (stages) of modules corresponding to a stimulus processing stage (input) and a response production stage (output). Notably, no processing can take place in the response-production stage until the activation has reached threshold in the stimulus-processing stage.

A self-fulfilling prophecy

There is a sense in which compatibility investigations that stem from a linear-stage information-processing viewpoint are self-fulfilling prophecies. Stimulus sets are arbitrary (shapes, symbols, colours etc.), response sets are arbitrary (e.g. digit key-presses, or even a 'green' response), and mapping rules are arbitrary (e.g. left key-press for symbol x, right key-press for symbol +). It is not surprising then, that many information-processing accounts tend to be arbitrary and invoke abstract groundless codes. The DO model for example, or accounts such as Weeks & Proctor's (1990) salient features model (which simply states that compatibility effects arise from a correspondence between salient features of stimulus and response sets) appear to offer plausible *descriptions* of relationships between stimulus and response sets, but do not offer a *reason* why such relationships should exist. Rarely is any attempt made to explain why the task irrelevant spatial stimulus dimension is coded in the first place (Umilta, 1994).

Exceptions to this include a referential-coding hypothesis (Hommel, 1993), which suggests that the irrelevant spatial stimulus dimension is coded on the basis of different frames of reference (egocentric or object-based); and an attention-shifting hypothesis (e.g. Nicoletti & Umilta, 1989, 1994) which suggests that that the irrelevant spatial stimulus dimension is coded on the basis of attentional orienting to the location of the imperative stimulus.

Stoffer and Yakin (1994) further propose that the relative spatial code is functionally related to the initial direction of attention upon stimulus onset, such that the position of attention acts as a reference point for spatial code formation. Because visual attention is geared to the control of eye movements, an attractive feature of attention-shifting hypotheses is their implication, at some level, of the action system in their explanation of the Simon Effect.

Indeed, a 'premotor theory of spatial attention' suggests that various cortical and subcortical areas act as neural maps that represent space (Rizzolatti, Riggio and Sheliga, 1994). These maps do not merely represent space however, as they serve the dual function of representing action. There is no linear stage sequence that requires the translation of spatial information into information for action, but rather a single representational system that simultaneously controls action (e.g. eye movements) and spatial attention. This kind of representational account appears to encapsulate what Clark (1997) calls 'action-oriented representations'. Clark (1997) describes action-oriented representations as neural maps that also act as controllers; they both describe a situation and suggest an appropriate reaction to it (this is also what the APH proposes). In this way, action-oriented representations are not dependent on separate representations of states of the world or the cognitive systems goals for behaviour (Chemero, 2000).

Summary of computational approaches

The information-processing tradition to which Marr's work and linear stage models of S-S-C and S-R-C effects belong, share assumptions of hierarchical information processing with strict dependency relations. This can be summarised as a sequence of input (perception) -> translation (cognition) -> output (action). This sequence (and the abstract nature of the codes proposed) ensures an indirect relationship between perception and action. The following subsection examines ecological accounts that assume a more direct relationship between perception and action.

1.2.2 Ecological approaches

Visual perception

Gibson (1979, p.1) expressed the essence of his argument as follows:

> "We are told that vision depends on the eye, which is connected to the brain. I shall suggest that natural vision depends on the eyes in the head on a body supported by the ground, the brain being only the central organ of a complete visual system."

By investigating vision within the context of a complete visual system, it becomes more natural to consider the problems encountered in terms of guiding behaviour, rather than in terms of creating general-purpose representations. Where Marr's approach fails to acknowledge sensorimotor involvement in a complete visual system (concentrating instead on the action-neutral recovery of a visual scene), those computational approaches that do consider the complete visual system (such as Ballard's 1991, 'animate vision', or Churchland et. al's 1994 'interactive vision'), still maintain a degree of separation between visual perception and action. Those in the ecological tradition regard such a divide as conceptual rather than real. Perception is seen as an activity rather than as a passive process, and the guidance of effective action within an environmental niche is taken to be the very essence of perception (rather than a temporally distinct consequence of it).

Affordances

Gibson (1979) invented the noun 'affordance' as part of the ecological lexicon to explicate the intimate relationship between an animal and its environmental niche. An affordance is a high-order property of an aspect of the environment (e.g. a surface or an object) taken with reference to the sensorimotor capabilities of the perceiver. These high-order properties can be understood in terms of affordances *only* when they are considered relative to the perceiving animal (see Figure 1.4). Thus an apple affords grasping and eating for a human, but not for a fish, and a staircase affords climbing for a human but not for a Dalek (as the sensorimotor capabilities needed for grasping or climbing are lacking).

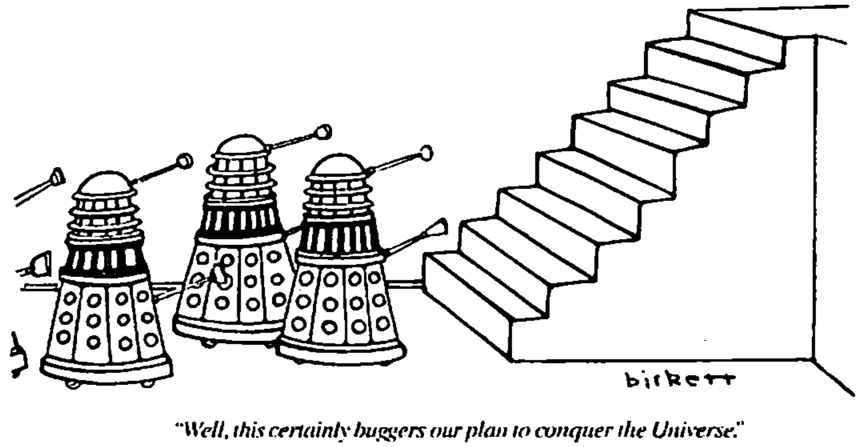


Figure 1.4 A staircase that does not afford climbing to Daleks (from The Punch Cartoon Album, 1991)

For Gibson, affordances are not purely objective (physical) properties of the environment, nor purely subjective (phenomenal) properties of the viewer, but both. The actual physical properties of an object (its size or shape etc.) that afford actions are defined as *distal properties* (and as such constitute *distal stimuli*), and the theory of affordances is essentially a theory of distal stimuli (Michaels and Stins, 1997).

Information that specifies affordances

Gibson argued that information about affordances is specified by 'invariances in the optic array' that are directly perceived (and not mediated by any information processing). The affordance-specifying properties of invariances in the optic array that are available to the visual system are defined as *proximal properties* (and as such constitute *proximal stimuli*).

In order to appreciate the important difference between an affordance (distal stimulus) and the information that specifies an affordance (proximal stimulus), it is helpful to consider what Gibson (1979, p.142) refers to as "misinformation for affordances". Consider a sheet of glass in a glass door, which serves as a barrier. The distal properties of this glass sheet (supported by the doorframe) afford for a human, collision, opposition, support etc. However, under specific light conditions one might walk straight into the glass door and injure oneself. Under these light conditions the information about what the glass sheet affords is insufficient or under specified. That is, the proximal properties of the light (the information) do not specify what the glass actually affords (e.g. collision) and thus the affordance is misperceived. Had there been some dirt or highlights on the surface of the glass, then the proximal properties of the light would have been sufficient to specify the affordance for collision.

The realisation that the locus for information about affordances (and its measurement) is in the optic array exposes a paradox in the ecological approach. Firstly, there is the holistic notion of an affordance (distal stimulus) that implies the "complementarity of the animal and the environment" (Gibson, 1979; p.127), that "cuts across the dichotomy of subjective-objective" and that "is both physical and psychical, yet neither" (Gibson, 1979; p.129). Secondly, there is the reductionist notion that this unity is somehow specified *exclusively* by invariant structures in the optic array (the proximal stimulus), so exclusively in fact, that this information is said to exist regardless of whether or not an animal is perceiving it. Furthermore, this information is directly picked-up by the viewer. Gibson (1977, p.249) explains the simplicity of his theory of direct pickup,

> "In the case of a persisting thing, I suggest, the perceptual system simply extracts the invariants from the flowing array; it *resonates* to the invariant structure, or is *attuned* to it."

It is in the second notion of proximal stimuli that Gibson's theory becomes notoriously untenable (see Ulman, 1979, 1980 and Fodor and Pylyshyn, 1981 for criticisms). Problems include just what might constitute higher-order invariant structures in the light (in stretching Gibson's theory to logical extremes, Fodor and Pylyshyn, 1981 speculated whether the Da Vincihood of a painting might be specified by such structures), and just how such information is directly perceived (by the ill-defined mechanisms of 'resonance' or 'attunement').

Perception-action couplings

Rather than viewing information in the environment as a source of input that is represented and transformed into detailed plans for action, ecologists (e.g. Michaels, 1988; Stins and Michaels, 1997) propose that information in the environment is a source of various parameters of stimulation that are tightly bound to (or coupled with) various parameters of action. Information is said to consist of geometric or kinematic patterns that are lawfully related to the environment. Attempts to uncover lawful relations that are coupled with actions have revealed that some informational characteristics of a visual scene or object are more useful to the viewer than others. For example, in a moving visual scene such as an apple that has been thrown towards the viewer, the apple has many measurable characteristics such as initial size, final size, expansion duration and so on, that may not be coupled to coordinated action (Michaels, 1988 made this observation with reference to a moving square). There is evidence that animals (e.g. Lee and Reddish, 1981) and humans (e.g. Bootsama, 1989) can use higher-order variables to specify time to contact such as Lee's (1976) tau (the ratio of momentary size to expansion velocity), and it is measurable variables such as these that are likely to be coupled with coordinated action.

Similarly, in a static visual scene, such as a photograph of an apple presented on the left of a screen (e.g. the 'apple experiment') there are many measurable characteristics (such as size, colour, location), some of which may or may not be coupled to parameters action. To take a simple example, the extent to which an apple located on the left may be coupled with a left hand response may be greater than the extent to which it is coupled with a right hand response. Clearly in distal terms, the photograph of a left located apple presented on a flat computer screen affords no actions whatsoever (other than perhaps pointing towards, or manipulation with a virtual tool such as a cursor). In fact Gibson (1979, p.283) refers to pictures or photographs of objects as "virtual objects", and in strict Gibsonian terms, it is the *misinformation* in the patterns light that can be misperceived as affording reaching and grasping. Here however, misperception of affordances would not appear to arise from perceiving under specified of insufficient information, but rather sufficient, or indeed over specified information.

Perception-action couplings and S-R-C

From an ecological perspective, in S-R-C experiments (e.g. the 'apple experiment'), it is the coupling of actions with the information specified by properties of the proximal stimulus that is thought to be responsible for compatibility effects. There is an action (e.g. a left key press or a right key press) that is, to a greater or lesser extent coupled to a perceptual event (e.g. a photograph of a red or green apple that is left or right located). Furthermore, this coupling often has some ecological validity in its correspondence to real-life events (e.g. a key press to a photograph of an apple can be considered analogous to the initiation of a reach movement towards a real apple). In this context, movement initiation times are taken to reflect the extent to which available information guides actions (rather than reflecting the number or complexity of information processing operations).

Consequently Stins and Michaels (1997) redefined S-R-C as information-action-compatibility (I-A-C).

Box 1.1 summarises a typical experimental task that reflects the tension between ecological (I-A-C) and computational (S-R-C) interpretations of compatibility effects. Despite the interpretation of effects remaining open to S-R-C or I-A-C accounts, the S-R-C paradigm offers a useful (if crude) technique for uncovering affordances (or at least, the misinformation for affordances), whether through the use of static visual displays (e.g. Stins and Michaels, 1997, 2000; Adam, Paas, Buekers, and Wuyts, 1996) or moving visual displays (e.g. Michaels, 1988; Stins and Michaels, 1999; Brass, Bekkering and Prinz, 2001).

Box 1.1 The problematic nature of interpreting compatibility effects

In Experiment 2 of Michaels (1988), participants made forward left or right pushes (likened to reaches or catches) of two joysticks that could be in one of three possible positions. Responses were made to the square that moved from two left and right positioned squares. The direction of apparent motion was ipsilateral (illustrated by the left side squares in Fig. a) or contralateral (illustrated by the right side squares in Fig. a). The pattern of results was as follows: 1) a spatial compatibility effect for responses made to the actual (i.e. initial) position of the moving square, 2) a similar yet larger effect when responses were made to the destination of the square, which was greatest when responses had an absolute rather than relative correspondence to square (that is, as shown in Fig. A, when joysticks were positioned at P2, rather than P1 or P3), 3) a Simon Effect of task irrelevant destination of the square, and 4) a reverse Simon Effect of task irrelevant actual position of the square.

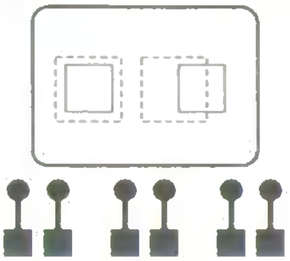


Figure A.

Figure B.

Michaels (1988) suggested these results demonstrated an affordance for catching a square at its absolute movement destination. Procter, Van Zandt, Lu and Weeks (1993) offered an alternative explanation, suggesting the coding of salient relative left-right stimulus motion and relative left-right response positions caused the effects. They showed experimentally the same pattern of results using stimuli that moved towards or away from the viewer and key press responses at various positions- all of which had little resemblance to 'catching'.

Michaels (1993) responded to this critique experimentally by adding a condition with a curvilinear moving square that terminated halfway through its trajectory (see Fig. b above). Thus relative left-right motion was opposite to actual destination, and the results revealed response- destination compatibility that suggested the influence of absolute rather than relative destination. Not to be outdone, Procter, Lu, Van Zandt and Weeks (1994) responded with a relative-direction coding account of the data, with reference to motion of the linear contralateral display relative to the new condition of a curvilinear display.

A self-fulfilling prophecy

There is also a sense in which compatibility investigations that stem from an I-A-C viewpoint are self-fulfilling prophecies (cf. earlier discussion regarding linear-stage information-processing viewpoints). Stimulus sets are ecologically meaningful (objects, surfaces, motion etc.), response sets are ecologically meaningful (e.g. pointing, reaching, pushing or pulling a joystick etc.), and mapping rules are ecologically meaningful (e.g. mapping rules that are task relevant rather than task-irrelevant). Even when arbitrary stimulus sets are used, the mapping rules and response sets are often transparent enough to ensure an ecological interpretation is possible. A good illustration of this comes from Adam et al (1996), whose results (speed and accuracy) reflected the comparative ease of pointing to one of four locations when compared to responding with one of four possible finger-lifts or to verbalising one of four numbers (see Figure 1.5). Such a result is hardly surprising, and nor are the conclusions drawn (*ibid.* p. 518),

> "...a pointing response to a spatially defined target stimulus, might invoke a low-level, *direct* perception-action routine, while a finger and vocal response might invoke a more cognitive, higher-level, *indirect* perception-*decision*-action routine."

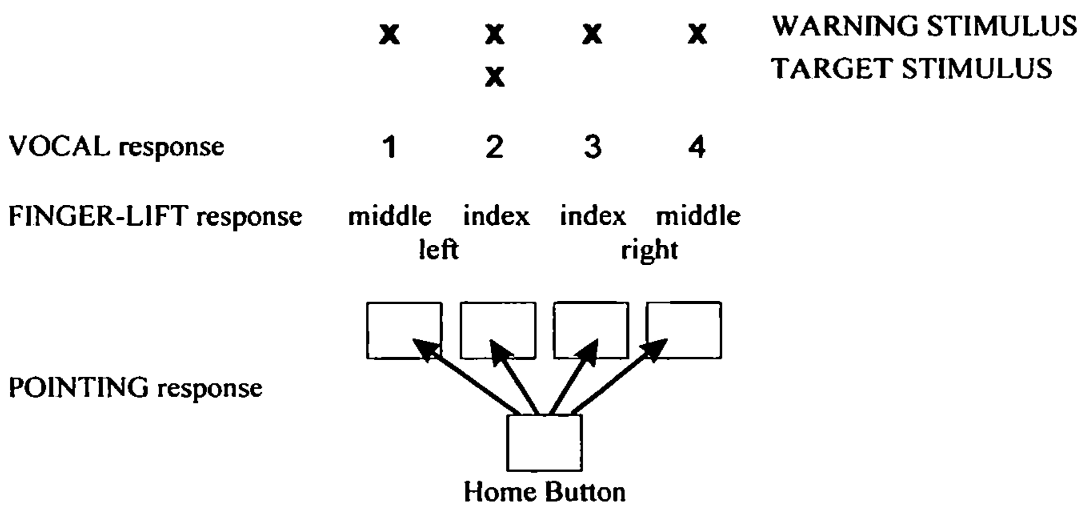


Figure 1.5 A schematic of the stimulus display and three response types (from Adam et al, 1996)

This kind of study is trivial in the same sense that one would not be surprised to find that people can coordinate a golf shot more successfully when swinging a golf club than when swinging a log.

Constraining degrees of freedom

Michaels and Stins (1997) summarised the ecological gist of perception-action as the perceiver-actor selecting goals and the means for achieving them, by bringing under control a few motor elements of an action from numerous initial possibilities. The problem is therefore one of constraining the degrees of freedom of an action. They suggested that the concept of constraining degrees of freedom (i.e. the constraint of a dynamical system) is quite different from that of setting parameters in a generalized motor program (i.e. the instruction of a machine). In constraining the degrees of freedom within a dynamical system, solutions appear to be 'soft-assembled' and under 'decentralised' control, rather than 'hard-assembled' (e.g. in terms of specific programmed instructions) and under 'centralised' control (e.g. via a detailed inner model).

As a case in point, Clark (1997) described the everyday example of human walking used by Thelen and Smith (1994). Rather than appearing to be driven by a set of precise movement commands (as is typical in say a classically programmed robot arm whose success depends on the precise control of programmed movement parameters), human walking appears to naturally compensate for dramatic changes in the problem space, such as icy terrain, blisters, high-heeled shoes and so on. Human walking is robust and fluid, and any surprises are coped with by recruiting different patterns of gait, muscle control, etc., while maintaining the gross goal of locomotion. More specialised, highly skilled behaviours that operate under exceptional real-time demands (such as professional skateboarding, snowboarding, rally-driving etc.) make for even more compelling cases of soft-assembled solutions to coordinated behaviour that are under decentralised control.

Links in a perception-action loop

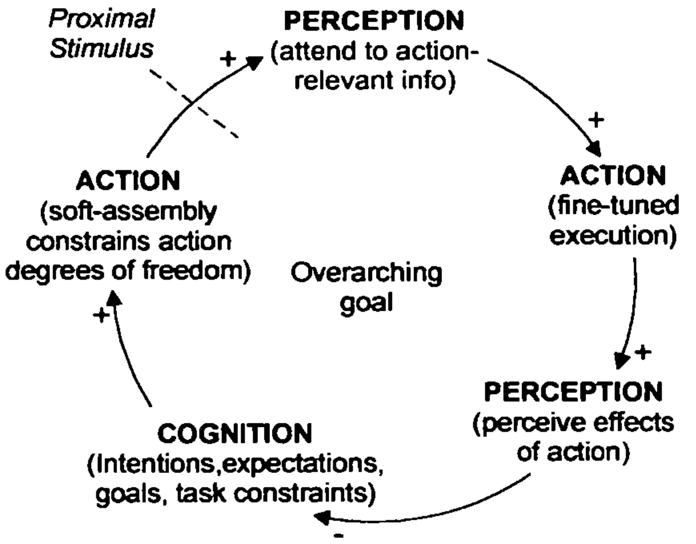
The concept of perception influencing action is a familiar one. Sensory information is perceived, and this influences action either directly (ecological view) or indirectly (linear-stage information-processing view). A less familiar concept (at least for proponents of classical theories of structure) is that action can influence perception. There is considerable evidence however, that this is the case (some recent examples include Hecht, Vogt and Prinz, 2001; Müsseler and Hommel, 1997; Craighero, Fadiga, Rizzolatti and Umiltà, 1999; Wohlschläger, 2000, 2001; Hommel, Müsseler, Aschersleben and Prinz, 2001; Stoffregen, Pagulayan, Bardy, & Hettinger, 2000). Indeed, action even appears to affect memory (e.g. Kerzel, 2001; Noice and Noice, 2001).

Some perception-action couplings (such as the activity of catching a butterfly) are quite obviously dynamic in the sense that perception and action are intimately caught up in an *ongoing* adaptation to real-time, on-line demands. In cases such as these it is clear that an action (moving the hands to catch the butterfly) can influence perception (the butterfly is perceived moving away from the hands to avoid capture). These couplings are appropriately described in terms of a perception-action loop, where perception influences action, which influences perception and so on. Gibson (1979) argued that this is what the activity of 'real' vision is all about, and not its various experimental approximations (for example, eye, head and body movements all affect what is perceived, and what is perceived similarly affects eye, head and body movements).

There is however a subtler sense in which action can influence perception, and this is well illustrated by Michaels and Stins (1997) review of Fitch and Turvey's (1978) analysis of baseball hitting. From an initially huge number of action degrees of freedom, once on the plate, the situational constraints of a stance and the intention for a hit to left-centre ensure that the possible degrees of freedom are dramatically reduced. The player's solutions to hitting the ball are soft-assembled, and will be adaptively fine-tuned to the actual details of the approaching ball. The organisation of the action is said to "set up" perception, and as Michaels and Stins (1997) explained, many action degrees of freedom are constrained by intentions and task demands, and these determine what information will be attended to. However, it is not clear just how action 'sets up' perception. Once again the mechanism of 'direct perception' is somehow involved in this causal connection.

These principles appear to be equally applicable to S-R-C experiments. In the 'apple experiment' for example, the situational constraints come in the form of a mapping rule, and the physical layout of key/hand configuration. A finger of each hand is placed on a response key, and as Michaels and Stins (1997) noted, because such tasks demand speed, the action (in this case for both hands) is presumably organised in so far as possible before the stimulus is presented. Thus responses are already to a greater or lesser extent 'soft-assembled' and these remaining degrees of freedom determine what optical information will be attended to that might constrain them further (such as information about apple location). The extent to which such information is effective in constraining action degrees of freedom is reflected in reaction times. Thus the 'apple experiment' (or any other similar S-R-C experiment) can be considered in terms of a perception-action loop.

Figure 1.6 describes two perception-action tasks in terms of a negative feedback loop - 1) a striker in a game of baseball, and 2) the 'apple experiment'. No attempt is made to open the loop to other causes that would almost certainly interact with it [e.g. 1) emotions, health, environmental conditions, the booing of the crowd etc., 2) the sound of the experimenter talking in the corridor, thought processes alleviating boredom etc.]. Consequently the process driven (intentions, goals, expectations etc.) loop presented is vastly oversimplified. It is however, important to note the loop's operational closure.



Links in loop	Process	E.g. Baseball	E.g. 'Apple experiment'
(+ve link) Intentions and task constraints -> constraining action degrees of freedom	(a) the task constraints, expectations and intentions, initiate (b) the soft-assembly of an action thus constraining action degrees of freedom	(a) initial stance, expectation of a slow curved pitch, and intention to hit ball to left-centre, (b) step and swing	(a) hand-key configuration, mapping rule, expectation of an apple picture, intention to react quickly, (b) left and right response
(+ve link) Constraining action degrees of freedom -> detection of stimulus	(a) the soft-assembled action/s, 'set up' (b) attention to action-relevant optical information	(a) step and swing, (b)[2] release of the ball (needed to initiate step) and time-to-contact (needed to initiate swing)	(a) left and right response, (b) location of the apple.
(+ve link) detection of stimulus -> fine-tuning of action/s	(a) the details of the action-relevant optical information attended to, inform (b) the on-line fine-tuning of the action/s	(a) information of release of ball and time-to contact, (b) execution of step and swing	(a) information of location (and colour to determine response) (b) execution of left response
(+ve link) fine-tuning of action/s -> perceive effects	(a) from carrying out the fine-tuned actions, the perceiver-actor perceives (b) the visual, auditory and tactile effects of actions	(a) step and swing-to-hit, (b) feel and sound of hit, sight of ball trajectory, speed, end position etc.	(a) left response, (b) feel and sound of response, sight of picture disappearing, sound of beep signalling mistake
(-ve link) perceive effects -> intentions and task constraints (note that this negative link regulates the loop cycle)	(a) perceiving the effects of action/s, influences (b) the task constraints, expectations and intentions of the perceiver actor	(a) feel and hear miss hit, ball landed short and wide of centre-left, (b) adjust posture, expect maybe a fast straight pitch next, intend to hit short and centre-right	(a) finger feels stiff, or slipped from centre of key, beep signalled mistake, (b) adjust body posture, realign finger to key, expect maybe a red apple next, intend to slow down response for accuracy

Figure 1.6 Possible links in a perception-action loop

[2] Stins and Michaels (1997) report that Fitch and Turvey (1978) speculated that this kind of information (release of the ball, time-to-contact) might be exploited. NB. Stins and Michaels (1997) fail to provide a reference for Fitch and Turvey (1978), but see Turvey, Fitch, & Tuller (1978).

The perception-action loop and linear-stage information processing

In their treatment of I-A-C, Michaels and Stins (1997) explicitly avoided a discussion of perception-action loops, arguing that perception-action couplings typical of reaction time tasks are fundamentally reactive. It has been argued above however, that a typical S-R-C experiment (e.g. the 'apple experiment') can be conceived of as a perception-action loop.

When S-R-C tasks are considered as simple (if contrived) instances of perception-action couplings, whose effects are derived from a single perception-action psychological process (whose usual functioning occurs within the context of a perception-action loop where, as Michaels and Stins, 1997 put it, one perceives to act and acts to perceive), it is hardly surprising that attempts to pin down the information-processing stage responsible for, say, the Simon Effect, have resulted in contradictory explanations (with Hasbroucq and Guiard, 1991 locating the effect at the stimulus-encoding stage, and Kornblum et al., 1990 locating it at the response-production stage).[3]

As with the Watt governor (described earlier in Figure 1.1), any element of a dynamical system (information-processing or otherwise) can be isolated and credited with a particular functional significance. For the governor, a positive link in the loop can be described as the flow of steam (cf. stimulus- encoding stage) determining the engine speed (cf. response-production stage), and the negative link in the loop can be described as the engine speed (cf. response-production stage) determining the flow of steam (cf. stimulus- encoding stage). Both are fairly accurate and useful descriptions, but neither one has more significance than the other in the loop. Indeed, other more accurate descriptions are possible (the distance between the weights specifies the flow of steam, or the governor speed specifies the angle of the arms which specify the distance between the weights etc.). In isolation however, no single description does justice to the dynamics of the process.

Just as it is difficult (if not futile) to separate a somehow privileged cause (input) from an effect (output) in the negative feedback loop of the Watt governor, so too is it difficult (if not futile) to separate perception from action (or input processing stages from output processing stages) in a perception-action loop.

1.2.3 Summary of computational and ecological approaches

Key assumptions held by computational and ecological accounts of perception (and its relationship with action) are summarised in Table 1.3.

Table 1.3 Assumptions of computational and ecological approaches

Assumptions	Computational	Ecological
Study of...	The mental	The observable
Models use...	Tools of information-processing	Tools of dynamical systems theory
Purpose of vision	To create general-purpose descriptions of the world	To effectively guide an animal in its environment
Mechanism of visual perception	Processing of information (symbolic or subsymbolic internal representations)	Resonance or attunement to information (invariants in the optic array)
Nature of perceptual process	Visual input is transformed into an elaborate representation via hierarchical stages of processing that have bottom-up dependency relations	A direct, unmediated process that utilises the complete visual system (eyes, brain, head, body)
Mechanism linking perception to action	Processing of information (symbolic or subsymbolic internal representations)	Attunement to action-relevant information (affordances specified in the optic array)
Nature of perception-action process	Visual representation is transformed into action via hierarchical stages of processing that have bottom-up dependency relations	A direct coupling of perception to action, characterised by a perception-action loop

[3] A similar argument can be made concerning S-S-C effects. Cohen, Dunbar and McClelland's (1990) impressive connectionist model of the Stroop effect (reviewed by MacLeod, 1991), while conventionally assuming a unidirectional flow of information from input to output, nevertheless recognised the importance of response processes in the Stroop task- a task typically interpreted purely in terms of stimulus processing. This recognition serves to emphasise the case made above for rejecting oversimplified analyses of individual processing stages at the expense of the wider picture.

Possible shortcomings of these approaches can be summarised as follows:

Computational approaches

- In tackling 'pure vision' there has been a failure to acknowledge the complete visual system and its role in guiding behaviour.
- The need for a 'fully elaborated representation' does not appear to be reflected by the real-time demands of 'interactive vision'. Often the world can act as its own best model (see section 1.3 for further discussion).
- Linear-stage information-processing accounts of vision and how it relates to action (the indirect, abstract nature of which is captured by coding accounts of S-R-C effects) do not reflect the dynamic nature of vision and its place in a perception-action loop.

Ecological approaches

- In placing the burden of information *entirely* in the optic array, the ecological concept of 'information' becomes untenable.
- The mechanisms of direct perception ('resonance' and 'attunement') are ill defined and almost mystical, perhaps inevitably so owing to the previous shortcoming. It has been proposed that similar mechanisms constrain a system's action degrees of freedom. As well as suggesting that upon stimulus presentation, perceptual systems "detect the information to which they are attuned", Michaels and Stins (1997, p.335) add to the explanatory vacuity of such terms by claiming that the perceiver-actor 'taps' information appropriate to constraining actions (this 'tapping' is analogous to the escapement mechanism in clocks that selectively taps potential energy at the right phase to sustain oscillation).
- On the basis of unconvincing notions of resonance, attunement and tapping, an outright rejection of alternative information-processing and representational approaches is inappropriate. As Marr (1982, p.30) wrote, "... the detection of physical invariants, like image surfaces, is exactly and precisely an information-processing problem". Indeed, there are good reasons to persevere with information processing, for as the next section argues, refined notions of representation answer many of the legitimate criticisms levelled at classical representations.

1.3 The Representation Debate

To reiterate the core idea of the APH, it is argued that simply looking at an object, regardless of (and in spite of) any intention to act upon it, partially activates motor codes that a) are related to components of the actions associated with that object, and b) form an integral part of a visual object representation. The APH shares obvious similarities to Gibson's theory of affordances, so much so that potentiated actions are termed *micro-affordances* (Tucker and Ellis, 2001; Ellis and Tucker 2001).

There are however, two important theoretical differences between affordances and micro-affordances. Firstly, *micro*-affordance refers to *elements* of an action that are afforded (such as a particular component of a reach or hand shape), rather than the all-encompassing Gibsonian affordance; such as the postbox that "...affords letter-mailing to a letter-writing human in a community with a postal system" (Gibson, 1979, p.139). Secondly, micro-affordances are realised in the *representation* of a visual object (whereas Gibson's affordances are distal properties of the environment that are not represented but directly perceived).

Actually, in saying what affordances are not ("Note that the size of an object that constitutes a graspable size is specified in the optic array. If this is true, it is *not* the case that a tactual sensation of size has to become associated with the visual sensation of size in order for the affordance to be perceived."), Gibson (1979, p. 133) came close to defining what is meant by micro-affordance. More than the perception of a size-related affordance occurring through associations that are sensation-based however, the APH requires that actions are directly involved in the visual representation of an object. It is therefore to representations and just what they might be that discussion now turns.

1.3.1 Different understandings of representation

It has been noted earlier that ecological psychologists and dynamical systems theorists reject the notion of representation. The following argues that such rejections are more appropriately directed towards detailed, fully specified representations (whether symbolic or connectionist), rather than towards refined notions of representation that emphasise content over structure (such as the action-oriented representations of the APH).

Classical Art and Classical Representations

Interesting parallels can be drawn between the debate in the scientific arena concerning what a representation is, and the debate in the artistic arena concerning what art is. Once trained as an art critic, these skills are applied to all things, including piles of bricks (discussed later). The same is true in cognitive science. An academic's training often shapes his or her opinions about representations. For example, researchers in areas such as psycholinguistics often fall into the symbolic representation camp, reasoning that language must surely be representational, with its symbols (words) and their relations corresponding lawfully to things and their relations in the world. Maybe then, thought itself is a language too, a single symbolic language of representations (e.g. Fodor, 1975).

With a painting or sculpture by Michelangelo (see Figure 1.7) there is an identifiable attempt to represent a person or an object that is structured and meaningful to both artist and observer and this would presumably qualify as an instance of art (and as is argued later, also qualifies as an instance of representation). Is this masterpiece equivalent however to a puddle of paint or to a pile of bricks? Similarly a symbolic representation, such as might be expected in solving a complex mental arithmetic problem, is lawfully structured and meaningful, and presumably qualifies as an instance of representation. Activities such as language, mathematics, predicate logic or chess playing are particularly amenable to this kind of explanation. They do not however exhaust the entire repertoire of human behaviour, and it is not clear why the mental processes involved in a child's ability to crawl should be treated as equivalent to a mathematician's ability to derive the square root of seventy-three[4]. Nevertheless, this has tended to be the case, and the Representational Theory of Mind (e.g. Fodor, 1997) makes no discrepancy between mental processes- they are all supposedly based on the principles of symbolic representation.

Several authors (e.g. Grand, 2000; Brooks, 1990, 2002; Clark, 1997; Harnad, 2001; Franklin, 1995) have expressed serious doubts that these language-like activities reveal the essence of intelligent behaviour. While a linguistic, action-neutral, planning and reasoning mind may reflect some of the needs of the 21st Century person, Homo Sapiens Sapiens actually emerged in and adapted to an entirely different environment to ours. Indeed, recent investigations suggest that the mammalian brain evolved through adapting to specific ecological and ethological niches (Brown, 2001; de Winter & Oxnard, 2001).

Figure 1.7 'The Creation of Man' (a fragment of the Sistine Chapel ceiling painted by Michelangelo, 1511-12)

If this argument is taken seriously, an understanding of how the mind works may be better served by examining behaviours that are common to other animals (such as sensing and acting in an environment). 'Embodied Cognition' for example (see Box 1.2), describes an approach that connects intelligence to the outside world via the body of the intelligent agent.

[4] Although it does make sense to assume that so-called higher-level abilities such as mathematics are cases of 'exaptation' (e.g. Dennett, 1995) or 'piggy-backing' (e.g. Clark, 1997). That is, biological machinery that has been coopted for new purposes (Buss, Haselton, Shakelford, Bleske and Wakefield, 1998), either by natural selection (exaptations) or as a fortuitous side effect of adaptation (spandrels). The Representational Theory of Mind, however, does not assume that this is the case.

Box 1.2 An overview of 'Embodied Cognition'.

An animal can be said to interact with its environment through experiencing it and through acting in it. It can be argued that to act effectively in the world requires an experience of it, and to experience the world fully requires acting in it. It is this circularity that sums up 'embodiment' proper, and in explaining cognition as a biological phenomenon, it is this perspective that makes sense of Maturana & Varela's (1989, p. 26) aphorisms of 'all doing is knowing, and all knowing is doing' and 'knowledge brings forth a world'.

Experiencing a world

Brooks' (2002, p.51-52) first principle of embodiment presents a phenomenal or experiential view, "A *situated* creature or robot is one that is embedded in the world, and which does not deal with abstract descriptions, but through its sensors with the here and now of the world, which directly influences the behaviour of the creature." This view is exemplified by the 'niche-dependent sensing' (Clark, 1997, p. 24) of Brooks' robot Herbert, whose can collecting behaviour emerges from its sensorimotor capabilities situated within its effective environment (a laboratory littered with drink cans). Sharkey and Ziemke (2000) termed this phenomenal view 'Uexküllian embodiment' after the biologist von Uexküll (1864-1944). Von Uexküll proposed that an organism's perceptual and motor worlds are brought together in its Umwelt (subjective or phenomenal world). Similarly, for Varela, Thompson & Rosch (1991) a 'phenomenological animal' has an 'inner' body with an experiential structure that provides the context for living.

Acting in a world

Brooks' (2002, p.52) second principle of embodiment presents a mechanistic or behaviourist view, "An *embodied* creature or robot is one that has a physical body and experiences the world, at least in part, directly through the influence of the world on that body. A more specialized type of embodiment occurs when the full extent of the creature is contained within that body." As an example, he suggests that a robot that repeatedly executes the same paint-spraying pattern is thus *embodied*, but not *situated*. Sharkey and Ziemke (2000) termed this mechanistic view 'Loebian embodiment' after the biologist Loeb (1859-1924). For Loeb the environment was seen to 'force' the behaviour of the organism, and Sharkey and Ziemke argued that under this view, the behaviour or dispositions to behaviour are grounded in the interaction between the agent and environment. Cognition is therefore embodied in the mechanism itself, and hence no separate cognitive apparatus is needed. Similarly, for Varela, Thompson & Rosch (1991) a 'biological animal' has an 'outer' body with a physical structure that provides the context for cognitive mechanisms.

Interactive accounts of vision also share this intuition, as does the APH. As mentioned in section 1.2.1, in treating vision as an explorative activity that guides actions (by virtue of a complete visual system), fully specified, 'picture-perfect' representations lose their appeal. Various experimental techniques support this shift towards "partial-representation per glimpse", "visual semi-world" or "minimal representation" views of visual perception. For example, during saccades, changes of object colour go completely unnoticed even if that object is integral to a current task (Ballard, Hayhoe and Pelz, 1995). Similarly, in reading moving windows of text, surrounding 'junk' text is not noticed (Rayner, Well and Pollatsek, 1980; O'Regan, 1990). Not everything, it would appear, is represented.

Experiments on 'change blindness' reveal a similar phenomenon. When the cyclic sequence of two photographs of a visual scene (e.g. a cityscape) is disrupted by some technique (e.g. splatters of pixels, a global flicker created by a blank screen, eye blinking, eye saccades), major changes in the second photograph (e.g. a large building is removed) are not noticed. Even when an observer is told that a change will occur it can take nearly a minute to identify the change, and furthermore, attention is needed to detect this change (e.g. Rensink, O'Regan and Clark, 1997). As Figure 1.8 illustrates, while change blindness does not necessarily imply that *nothing* is represented (but see O'Regan, 1992; O'Regan and Nöe, 2001; Brooks, 2002), it does raise issues about the temporal nature of representations and what level of information might be preserved across views.

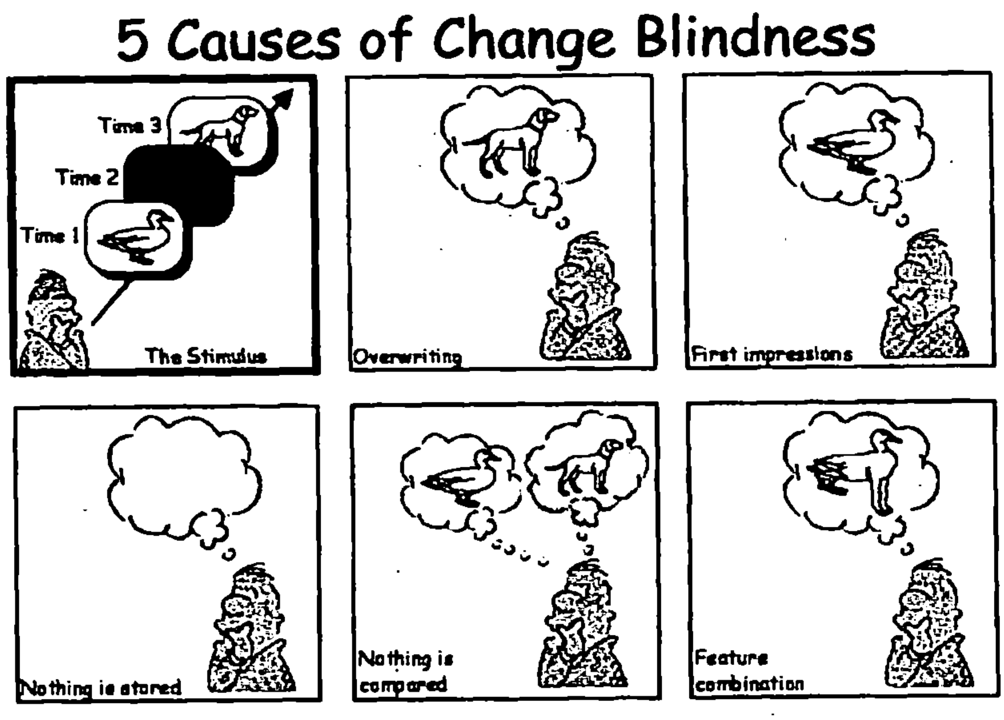


Figure 1.8 Five explanations of change blindness from Simons (2000). The 'thought bubble' indicates the content of the person's accessible representation of what was seen.

Minimalist Art and Minimal Representations

As suggested earlier, much animal behaviour, and similarly art, may require different kinds of explanation. Consider for example Carl Andre's (1966, 1976) sculpture entitled 'Equivalent VIII' (see Figure 1.9). For some, the arrangement of 120 American firebricks was considered an "insouciant masterpiece," (e.g. the London Sunday Times), while for others it was a "pile of bricks" (e.g. the Evening Standard). Whether or not it counts as art is still a contentious issue, but in the midst of the controversy there is a voice of common sense pleading that *if* it is art, it is not very sophisticated art, and it is surely not worth £2000,000. For all the clever meanings one might attempt to bestow upon it, it is for the most part, simply a pile of bricks.

Figure 1.9 'Equivalent VIII' in Tate Gallery (London), by Carl Andre (1976)

Similarly, in the midst of controversy over representations, there is a voice of common sense (e.g. Clark, 1997) pleading that for many behaviours, *if* they involve mental representations, they are not very sophisticated ones (personalised, multiple, partial, minimal, or action-oriented representations), and nor should they cost much (in terms of computational resources). For all the sophisticated representations one might bestow upon a person negotiating a crowded room, s/he may nevertheless simply be negotiating a crowded room. That is not to say *nothing* representational is going on, but it may be far simpler than expected. As Simons (2000) noted, across views minimal information (e.g. object location) may be preserved for guiding actions (e.g. "just-in-time" models such as Ballard, Hayhoe, Pook and Rao, 1997), but the details of visual features may not be preserved. There may be no route planning, or specialised map building, or distance calculating, or hypothesis forming, or in short, classical representing. Indeed, this is just what Grand (2000) and Brooks (1991) concluded from their autonomous agents that could successfully negotiate environments without anything resembling a classical symbolic representation.

Insights from contemporary Artificial Intelligence

Grand's Artificial Life 'Creatures' for example, are built with meticulous bottom-up detail, with their own simulated brains and physiology. They experience life in an environmental niche of food, objects and a limited ecosystem (i.e. they are situated), and their behaviours are driven by the interaction of their bodies with the environment (i.e. they are embodied). In accounting for their remarkably adaptive behaviours, Grand (2000, p.172) explained that, "The thoughts are not programmed in- the behaviour of the whole structure is not imminent in any of its parts but an emergent consequence of many tiny, concurrent, 'thoughtless' interactions, tuned by nature." Grand's Creatures are certainly representational, since they have program scripts for sequences of walking movements and 'concept' neurones that can 'wire themselves up' to represent new situations. Nevertheless, these are minimal, personalised representations (e.g. Ballard, 1991), such that 'something edible is moving towards me' might be encoded, rather than 'something green and edible was moving towards me on Tuesday and I was bored'.

That intelligent-looking behaviour is both emergent and under decentralised control (rather than fully specified and under centralised control), is a familiar feature of both ANN's and the perception-action loop discussed earlier. It is also inherent in the behaviour-based robotics of Brooks. Brooks (1991) denied his robots used representations because their high-level behaviours were not reflected directly in any of the simple computations they carried out. His autonomous insect-like robot Genghis, for example, can fluidly negotiate complex environments by simply connecting 'perception' to action in each layer of a 'subsumption architecture' that was built using 51 augmented finite-state machines (AFSM). These small, simple programs (none more complex than might be used in a electronic drink dispenser) were connected in parallel by fixed wires. Some AFSM's were directly connected to a motor, and the output of a given AFSM could provide input to another AFSM, activating it or inhibiting it. The little information that was passed occurred exclusively over outputs and inputs (one AFSM could not read the contents of another). The layers were hierarchically organised, with later more complex capabilities built on top of earlier simpler capabilities (which nevertheless remained fully operational). These higher layers could subsume the activity of lower layers, taking over as environmental events dictated.

The crucial implication of Brooks' work is this- *if* it is accepted that simplistic autonomous robots get by without representations, could the same be true for us? While the embodied approach may convince us that learning to accomplish progressively more abstract tasks involves building on bodily experiences, some of these tasks (especially language) may only be understood by resorting to some form of representation (Brooks & Stein, 1993). One such task might be simulating future scenarios. Genghis is very much a reactive creature, not a predictive one. It could not for example simulate the pitfalls of a particular path, choosing instead a more appropriate one before embarking on its travels. To illustrate this point, consider Dennett's (1996) intentionally oversimplified attempt to describe the evolutionary design options for various brains (see Figure 1.10). Although Genghis has no 'brain', the principles behind its subsumption architecture allow us to extrapolate anyway that it appears to be nothing more than an artificial Darwinian creature (all of its behavioural capacities are hardwired and no learning takes place). Brooks' (1991) occasionally radical anti-representationalist claims however, extend well beyond Darwinian creatures to Gregorian creatures (us). Aside from being too simplistic, a related caution against reading too much into physical robots such as Genghis is the preclusion of developmental or evolutionary perspectives. As humans build these robots there is no examination of the ongoing interactions between the central nervous system, organism and environment in the development of complex behaviours (Pfeifer, 1999, 2001).

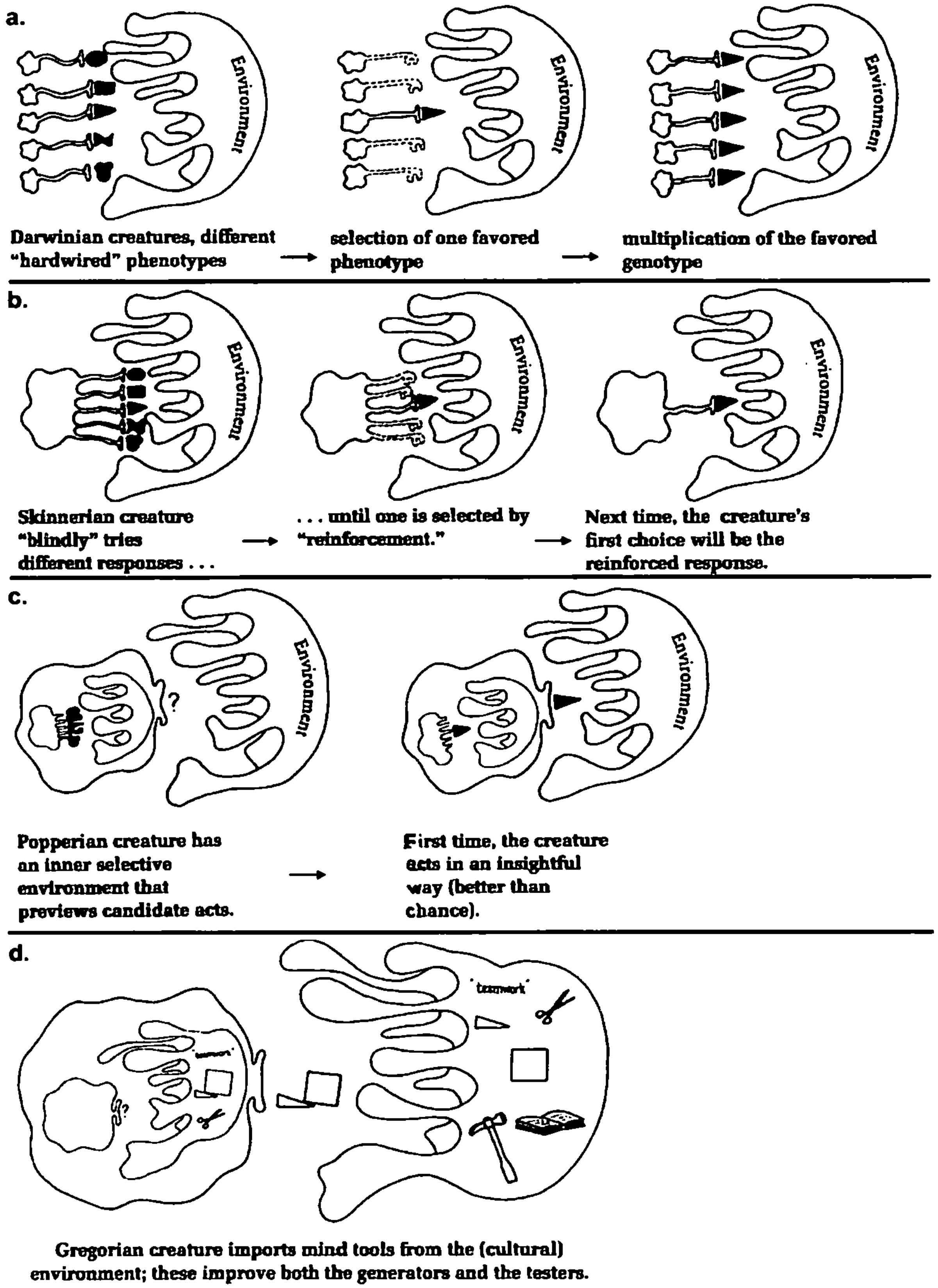


Figure 1.10 Design options for brains (adapted from Dennett, 1996)

For Dawkins (1976), the most profound mystery facing modern biology concerns how humans evolved a capacity to simulate the future (which he speculated, has culminated in subjective consciousness). Genghis, it would appear, does not convince us that such a capacity is possible without representations. In Chapter 2 a number of embodied approaches to cognition are reviewed that suggest a kind of anticipation or potentiation allows us to select from various possible actions in a given context, without calling upon conscious simulation or imagery. Those approaches that are explicitly representational nevertheless use minimal, action-oriented representations.

Furthermore, when imagery, simulation, or a more recent notion of emulation are explored, Dawkins' 'profound mystery' turns out to be a closely related project (if not the very same project) to that of understanding the links between perception and action (see Barsalou, 1999; Richardson, Spivey and Cheung, 2001). Kosslyn and collegues[5], for example, have shown in various neuroimaging studies (and other sources of evidence, such as studies of brain-damaged patients and studies of the effects of transcranial magnetic stimulation), that imagery draws on mechanisms used in other activities, such as perception (even as low-level as the primary visual cortex) and motor control (see also Jeannerod, 1995). It is argued that imagery is produced when perceptual and motor processing areas are activated from 'top-down' influences, and furthermore, imagery is believed to assist perceptual processing by providing an additional source of information when perceptual input is incomplete.

Grush (2002) on the other hand, argues that imagery and perception are not two separate processes where one can aid the other, but rather two modes of operation of the same process. This process is described as the continual updating of an estimate of the state of the environment and the primary perceptual areas. During perception this process is influenced by sensory information, whereas during imagery it is not. By appealing to the

[5] E.g. Kosslyn, Albert, Thompson, Maljkovic, Weise, Chabris, Hamilton, Rauch and Buonanno (1993); Kosslyn, 1994; Kosslyn, Thompson, Kim and Albert (1995); Kosslyn, Ganis, Thompson (2001)

same process, Grush argues that his theory of emulation[6] can account more readily for the intimate relations imagery and perception have to motor processes. Rather than a general observation that motor areas are active during visual imagery, the theory predicts (and has empirical support, e.g. Wexler, Kosslyn and Berthoz, 1998) that motor areas that are active are those areas responsible for the motor commands that are used in producing actual overt movements (such as might correspond with the imagined event).

Bearing in mind the close relations between imagery, perception and action, it is reasonable to hope that Brooks' subsumption architecture might nevertheless provide a good foundation for producing imagery or simulation-like behaviours. Indeed, Stein's (1994) MetaToto uses its subsumption architecture to build an internal map of its environment, such that it can select from a variety of 'imagined' possibilities. This map is built as real exploratory behaviour unfolds, such that the sonar it uses to act in and navigate around its environment is simulated (or perhaps more accurately, emulated) so as to explore a virtual world. After using this map off-line, MetaToto can engage its sensors and motors online to find a target location that it has only ever visited in a virtual context. So, although derived from its subsumption architecture, MetaToto does appear, in a tangible way, to represent its environment. As Stein (1997) explained, the robot "imagines" wandering around in the environment; an environment which is *represented* by a map that functions as though it were navigating in the real world.

[6] While Grush's (2002) 'emulators' are relevant to many of the issues discussed, they are beyond the scope of this Introduction. In short, an emulator is a proposed neural mechanism that mimics the input-output function of some system in such a way that creates, both online and offline, a mock sensory feedback (that is much faster than real sensory feedback) of interactions between internal systems or a sensory system and the world.

1.3.2 Defining representations

In appealing to the above arguments, a definition of representation is needed that is broad enough to accommodate personalised, multiple, partial, minimal, and action-oriented representations. Clark (1997, p.147) suggested that we call a processing story representational,

> "... if it depicts whole systems of identifiable inner states (local or distributed) or processes (temporal sequences of such states) as having the function of bearing specific types of information about external or bodily states of affairs..."

In elaborating on this view, Table 1.4 presents a teleological definition of representations that complements Clark's position. Three conditions (R1- R3) are identified that are deemed necessary (and sufficient) for something to count as a representation:

Table 1.4 Three conditions necessary for a representation, adapted from Chemero (2000), (previously adapted from Millikan, 1984)

	A feature R_0 of a system (S) counts as a representation for S if and only if the following conditions are met:
R1	A representation must be part of a system of representations. Thus, there are in addition to R_0 transformations of R_0, $R_1 \ldots R_n$, that have as their function to adapt the representation consumer to corresponding transformations of A_0, $A_1 \ldots A_n$.
R2	R_0 stands between a representation producer and a representation consumer that have been standardized to fit one another. That is, R_0 serves as a representation within the context of representation producing and consuming devices
R3	The proper function of R_0 is to adapt the representation consumer to some aspect A_0 of the environment, (such that S behaves appropriately with respect to A_0 even when A_0 is not the case)

It is notable that the above definition is concerned with content over structure, thus allowing a far broader range of representations than would be allowed under a structure-based definition (for example an insistence on combinatorial structure would leave little room for anything other than symbolic representations). Table 1.5 demonstrates how this definition fairs using examples we have encountered earlier. It is of interest that according to Table 1.5, Genghis *does* use representations (despite them in no way resembling classical symbolic representations). Furthermore, micro-affordances count as representations, and in a useful sense inanimate objects such as paintings or sculptures also count as representations by virtue of the intentional states of the artist. Accepting Genghis or paintings as representations raises several issues, which are discussed below with reference to each of the three conditions of representation.

Table 1.5 Examples of representation and non-representation

Examples	R1: content that is complex	R2: content that can be consulted	R3: content that has a specific function	Conditions satisfied
Michelangelo's 'Creation of Man'	It is part of a system of representations loosely defined as art	There is a representation producer (artist) and a representation consumer (us)	It is supposed to be painting about the 'Creation of Man'.	3
Andre's 'Equivalent VIII'	It is part of a system of representations loosely defined as art	There is a representation producer (artist) and a representation consumer (us)	It is supposed to be sculpture of *something* meaningful. However, what this meaning may be is not accessible to everyone	3
A puddle of spilt paint	It is not part of a system of representations loosely defined as art	There is no representation producer (e.g. the wind blew over the paint tin) but there is a representation consumer (us)	It is not supposed to be a puddle of paint, it just is. It has no function, meaning or purpose.	0
Genghis	It is part of a system of representations (there are inner states that exhibit a systematic kind of coordination with a whole space of environmental contingencies)	There are representation producers (AFSM's) and representation consumers (other AFSM's)	Each behavioural layer has a function (stand up, involuntary step, voluntary walk, walk over obstacles, walk competently, chase prey)	3
Micro-affordance	As above	There is a representation producer (the visuo-motor system) and a representation consumer (the cognitive and motor systems)	It has the function of representing possibilities for action	3

Content that is complex (R1)

Firstly, there must be whole systems of representations in order to give the content of a mental process sufficient complexity to merit a representational explanation. For Clark (1997) this condition is met by "... inner states that exhibit a systematic kind of coordination with a whole space of environmental contingencies" (*ibid*, p.147), but is not met by cases of simple causal correlation between a mental state and an environmental (or bodily) state, or cases of simple 'adaptive hookup' such as a light-seeking robot or a sunflower that has the *sole* function by evolution, design or learning, of coordinating a behaviour with an environmental contingency.

This is possibly the least contentious condition. Clearly if a system cannot represent more than one thing there is little point in calling that system representational. Art, as a system of representations, meets this criterion. That Genghis might represent is at least in part dependent on it having a range of possible internal states present in its behavioural layers.

Content that can be consulted (R2)

Secondly, there is no point in requiring a certain level of complexity unless this complexity can be used. For Franklin (1995) the only way this can happen is if representations are consulted for their content. Thus, implicit to having whole systems of representations, Clark (1997) suggests that we think of a representation as a kind of inner code that can be read by other systems that need to be informed.

A literal reading of the 'consultation' or 'reading' of inner codes raises the problem of dualism, a major criticism of representations. It implies that there is some kind of homunculus doing the consulting or reading. This is particularly so for 'look-up tables' of the sort proposed in Kornblum et al's (1990) DO model. Just what privileged component of a system has the ability to 'look-up' some information? The most obvious candidate for a homunculus in a symbolic system is the central executive. In Genghis however, no one part of the system is 'in charge', and furthermore, one AFSM cannot 'read' the contents of another; it is simply activated or inhibited by the value of another AFSM's output, passed along a fixed wire. Similarly, it is not obvious what is 'read' or what does the 'reading' in a micro-affordance. A partially activated motor code for example, appears to be nothing more than one of Grand's (2000) 'thoughtless' interactions between perception and action. It is simply an element in a complex flow of information.

An attractive feature of ANN's is their lack of a central executive. Control is instead achieved in a distributed fashion. For example, 'content addressable memory' (e.g. McClelland and Rumelhart's, 1981 word recognition network), allows a degraded or partial input (such as a couple of letters of a word) to trigger distributed patterns of activity that settle on content (e.g. a word) that is meaningful (to us at least). The distributed database of words in such a network is not 'read' or 'consulted' as might be the case in a traditional database.

In merely requiring a representation producer and a representation consumer however (see R2 in Table 1.5 above), these unwanted connotations are avoided. 'Reading' of information can be relaxed to a 'passing' of information. A representation producer *produces a product* (e.g. a numerical value outputted by an AFSM), which is consumed as an input (e.g. by another AFSM). One AFSM does not 'need to know' the details of another AFSM's informational content, it just 'needs to know' what the product of that content is (e.g. does the 'chase prey' layer need to be activated? Yes or No?). In this sense, there is active producing accompanied by passive consuming, and the product of an AFSM is content *bearing*, but is not itself content *laden*. It is in this context that the following sentiment of Grand (2000) makes sense- information acts on the brain at least as much as the brain acts on information.

Content that has a specific function (R3)

Thirdly, a representation should have a specific function- it is *supposed* to represent something. For Clark (1997) this means that regardless of the proposed nature of representations (e.g. classical or connectionist), correlations between bodily or environmental states and mental states should be used in such a way that suggests the system of inner states has the specific function of carrying specific types of information. Boers (2002) for example, suggested that waving patterns in reed do not represent wind direction or speed, because it is not a functional property of these patterns to do so. The notion of function is intimately tied to notions of meaning or intentionality, and this has both practical and philosophical implications that are discussed in the following section.

1.3.3 The function of representations

The illusive nature of representational functions

From a practical point of view, it can be hard to ascertain the specific function of a representation. Just what Andre's (1976) 'Equivalent VIII' is supposed to represent is anyone's guess. Andre presumably intended it to be more than just a pile of bricks, so it qualifies as a representation because it has a function or meaning (even if this meaning changes from person to person, context to context, and even if these meanings do not relate to André's own original understanding).

Chemero (2000) argued that action-oriented representations are problematic because it is difficult to say exactly what they represent. While it can be said that an action-oriented representation (e.g. a micro-affordance) has the dual function of providing featural properties of objects and affording actions towards them, it is not easy to say exactly what is being represented. As Chapter 2 argues at some length however, this is precisely the point that makes action-oriented representations attractive. Their function is neither static nor prescribed, and consequently one would not expect to find a definitive answer to what, exactly, it represents. It is the *behavioural activity* (in accordance with Brooks' intuitions) that gives a representation its function, rather than some highly specific pre-determined function.

The core problem with the 'brain as computer' metaphor is that the digital computer was modelled on the outward appearance of mental processes, rather than the structures that give rise to them (Grand, 2000). However, when a 'brain-as-Genghis' metaphor is adopted, it is similarly hard to identify function from the numerous tiny parallel computations. Brooks & Stein (1993) recognised that approaches such as theirs suffer from being inscrutable in so far as there is little explicit structure that can be described by abstraction. Although unhelpful, it may well be that this inscrutability reflects the way the brain represents. Although Brooks (1991, 2002) argues that there is nothing in any of Genghis' layers that has the function of representing, he nevertheless speaks freely of behavioural layers having the function of 'chasing prey', 'walking competently' and so on. He maintains the view that the complex behaviours of his robots only *appear* to reflect representations to him as an observer.

Nevertheless, contrary to Brooks' views, not all of our observations are necessarily misleading. Dennett (1995) for example, argues that an intentional position is essential. By looking for semantic-level facts one can explain the causal regularity of patterns. One would be left baffled by the long necks of giraffes, if every causal fact in the history of all giraffes that ever lived were to be described in micro-detail (c.f. trying to explain every causal fact in Genghis' history of computations). Dennett argues that going up an explanatory level or two, one can look for reasons nature might have had for the long necks of giraffes. In this light it is not an empty claim to say that a behavioural layer in Genghis has the function of representing prey. After all, the various behavioural layers were carefully designed to correspond to likely "stable plateaus of performance that evolution might find" (Brooks, 2002, p.244). Similarly, it is not an empty claim to say that in certain behavioural contexts an action-oriented representation (e.g. a micro-affordance) has the function of affording a power grip or a hand of response. The actual micro-details may not be forthcoming, but it is a sensible level of enquiry to start out with (although see below for a cautionary note).

Apparently obvious representational functions

The function of a representation is not always illusive. The more Classical looking the representation, the easier it is to identify its function. Michelangelo's 'Creation of Man' for example, aside from its historical connotations, self-evidently has the function of representing the outward appearance of the male form. This is analogous to clearly describable symbolic representations that model the outward appearance of mental processes. Thus for Kornblum et al's (1990) DO model, there is an identifiable 'activating function' that is then processed via an identifiable 'confirmation function'.

A semantic-level interpretation of the so-called 'bug-detectors' in frogs suggests that they have the function of representing prey. However, such obvious functional assignations do not come without a philosophical price. Dretske (1988) suggested that natural representational systems have indicators (e.g. the indicator mechanism in frogs that indicates small, black, moving dots), some of which have their own natural functions (e.g. the frogs indicator mechanism has the function of indicating prey). Through natural selection a particular set of indicators (the frogs neural 'bug detectors') have been adapted to serve the function of indicating prey. These intrinsic indicator functions are derived from their development and use within the system, and it is *only* when it is an indicators natural function to indicate what it indicates, that it achieves representational status.

However, as Dennett (1995) points out, when this frog is taken out of its natural setting, determining its representational function is not so simple. The frog readily flicks its tongue to dried pellets rather than flies. Because its 'natural function' is to represent prey (flies), it cannot be said to 'represent' dried pellets. Furthermore, what if the frog's offspring is born in a laboratory of dried pellets. Does this frog represent dried pellets? What if some frogs are more successful pellet detectors than others, and as a result their progeny is strong? In this case, there has been genuine selection for pellet detection, and this presumably counts as a natural representational function of indicating pellets. Thus some frogs are said to represent pellets and others are not, yet as Dennett notes, it seems unlikely that the eyes of 'prey representing' frogs tell their brains something different to those of 'pellet representing' frogs. Similarly, it would seem unlikely that, in terms of micro-affordances, a person brought up exclusively on an orange plantation, would fail to represent the possibilities for a grasp when confronted with a previously un-encountered apple or cricket ball. What one might instead expect is that the grasp-related properties of an orange can be generalised to other objects with similar grasp-related properties.

Derived Intentionality

What might be needed is an ability to *abstract* behavioural relevance from an infinite set of possibilities (e.g. from instances of pellets to flies or oranges to cricket balls...). Thus an abstraction of behavioural relevance for a frogs bug detector might simply be an object's size (which is of course shared by many objects such as small black dots, bugs, flies, pellets, raisons and so on)[7]. Similarly an abstraction of behavioural relevance for a micro-affordance might also simply be an objects' size (such as a small size for a precision grip, or a large size for a power grip), or its orientation, texture, location etc. Chapter 2 explores this issue of abstraction when it discusses various 'higher-order' approaches to perception, action and cognition that deal with a level of coding that is abstract (but crucially, not arbitrary).

In this light it makes little sense to talk of a natural function, such that a frog can be said to represent flies, but not pellets. What the function of a representation is depends on a history of interactions with the world and the context of a current behavioural activity. Dennett's (1995, p.408) views on intentionality are in agreement, "Meaning, like function, on which it so directly depends, is not something determinate at birth. It arises not by saltation or special creation, but by a (typically gradual) shift of circumstances". Thus over time sensorimotor associations serve the function of representing objects (flies, pellets, oranges, apples or balls), and this function is meaningful in the sense that it is effective in guiding

[7] For this reason a frog will starve itself to death flicking its tongue out at small moving black dots in a laboratory.

actions in a particular environmental niche. Thus, as Tucker and Ellis (2000) suggest, during development, associations 'come' to represent visual objects.

Intentionality is 'derived' rather than 'original', and viewing intentionality in this light provides a tangible basis for 'grounding' representations to their referents. Connectionism has typically failed to do this. Smolensky's (1988) classic paper, 'On the proper treatment of connectionism' made what Lakoff (1988) considered to be a huge omission- the body. Smolensky had failed to acknowledge that the neural networks in the brain connect to the sensorimotor system, thus falling victim to the 'symbol-grounding problem' (e.g. Harnad, 1990). Rather than seeking intentionality or meaning in the optic array (e.g. Gibson, 1979), or in an action-neutral brain (e.g. Smolensky, 1988), or on Twin Earth (e.g. Putnam, 1975), intentionality is sought in agent-environment interactions.

1.3.4 Summary of representations

The major objections to representationalism held by several approaches to cognition (e.g. dynamical, ecological, artificial life, real world robotics) appear to target detailed, fully specified representations that are exemplified by Classical symbolism. However, a range of alternative representations (personalised, multiple, partial, minimal, or action-oriented) appears to withstand much of this criticism. Action-oriented representations are particularly appealing because they ground themselves to their referents in the world through action.

When representations are suitably defined, Genghis, an intriguing case study against representations, actually appears to be representational after all. Regardless of whether this is accepted, it has been argued that Genghis is merely an artificial 'Darwinian Creature', and as such does not pass as a sufficient model for human cognition. This does not however, close the door for more sophisticated automata that might be built using the principles of subsumption architecture (e.g. MetaToto).

Suitably defined representations satisfy three necessary and sufficient conditions:

1. Content that is complex (a representation must be part of a system of representations).
2. Content that is accessible (content 'bearing', rather than content 'laden' information is produced, and can be passed to a consuming device such as the motor system).
3. Content that has a function (rather than specific or optimal, this function need only be viable within the context of a history of interactions and a currently exercised behavioural activity. This function can be legitimately sought through semantic-level investigations). This view is developed further in Chapter 2.

When these three conditions are met, representations can complement embodied approaches to cognition, which appeal to the temporality of cognition through a history of lived interactions between an embodied agent and its environment. It should however be noted that any number of other definitions could be generated that might not accept that Genghis, or humans for that matter, use representations. Thus a sensible position held by Clark (1997) is to acknowledge that talk of representations is an explanatory 'gloss', albeit a useful and perhaps essential one.

2. Seeing the wood for the trees

Contents

2.1 Introduction

That, perception, cognition and action are often studied in isolation (and, as Chapter 1 noted; linked via separate stages of information processing) is symptomatic of an underlying tendency in cognitive science to treat different faculties of the brain as legitimate isolated units of study. Grand (2000, p.142, 143) referred to attempts to separately solve individual aspects of intelligence and then somehow slot them together as the 'outside-in approach'. He concluded that,

> "...an elephant has skin like parchment, a trunk like a serpent and makes a noise like a foghorn, but wrapping a cobra round a lighthouse containing the Magna Carta does not give you an elephant...As usual, reductionism rules, and nobody can see the wood for all the trees".

This chapter concentrates on the wood rather than the trees by discussing a variety of approaches that seek some principled rather than piecemeal way of explaining how the brain might engage in perceiving, acting and thinking. As a general observation, when the wood is sought, the perception-action-cognition story that emerges closely resembles the loop described in Chapter 1, and there is no recourse to linear stage information processing. What is more, fully specified internal representations do not feature, and any talk of representations is necessarily of the action-oriented kind. Following discussions of separable-but-linked views (section 2.2), through to various unitary approaches of perception, action and cognition, (sections 2.3 and 2.4), it is argued in section 2.5 that the APH can be seen as compatible with all the various approaches discussed. Attention, however, is drawn to the ambiguity that surrounds the sources of data that are thought to support the APH.

2.2 Separable-but-linked perception-action perspectives

2.2.1 Interacting senses

Rather than sensory modalities functioning in a perceptual vacuum (as seems to be implicitly assumed by theories of 'pure vision'), the insights gained from cross-modal investigations appear to favour integrative (or at least interactive) perceptual mechanisms (see Table 2.1).

Table 2.1 Some examples of cross-modal interactions

Authors	Cross-modal influence of...	On...	Type of evidence
McGurk & MacDonald (1976)	Vision	Auditory perception	Subjective report (phoneme identity)
Finney, Fine & Dobkins (2001)	Vision	Activity of auditory cortex in the deaf	Functional magnetic resonance imaging
Doyle & Walker, (2002)	Vision, audition and touch	Saccade target selection	Behavioural (saccade trajectories)
Kennett, Taylor-Clarke & Haggard (2001)	Vision	Spatial resolution of touch	Subjective report (tactile two-point discrimination thresholds)
Taylor-Clarke, Kennett & Haggard (2002)	Vision	Spatial resolution of touch	Somatosensory event related potentials (ERPs)
McDonald, Teder-Salejarvi & Hillyard, (2000)	Vision and audition	Cross-modal spatial attention	Psychophysical
Eimer & Schröger, (1998)	Vision and audition	Cross-modal spatial attention	Visual and auditory ERPs
Eimer & Driver , (2000)	Vision and touch	Cross-modal spatial attention	Visual and somatosensory ERPs
Eimer, van Velzen & Driver (2002)	Vision, audition and touch	Cross-modal spatial attention	Visual, auditory and somatosensory ERPs

The nature of these mechanisms is as yet unclear. Whether or not a particular modality is relevant to the task appears to be important. For example, when touch was task-relevant, modulation of activity in the somatosensory cortex by non- (tactile) informative vision was increased (Taylor-Clarke, Kennett & Haggard, 2002), whereas when tactile stimuli were task-irrelevant, touch was decoupleable (i.e. no modulation of somatosensory activity) from attentional orienting within the visual and auditory modalities (Eimer & Driver, 2000). Cases like these appear to suggest what Eimer, van Helzen & Driver (2002) refer to as the 'separable-but-linked' view, where perceptual processing (e.g. spatial selection) primarily arises from the task relevant modality and then spreads to others.

On the other hand, the similarity between patterns of ERP modulations in different modalities (touch, audition and vision) for shifts of spatial attention (Eimer, van Helzen & Driver, 2002); together with evidence that *some* modalities (i.e. vision) cannot apparently be decoupled from attentional orienting within other modalities (i.e. audition and touch, Eimer & Schröger, 1998) suggest a role for supramodal perceptual mechanisms. Indeed, from a radical ecological viewpoint, Stoffregen (2000) and Stoffregen & Bardy (2001) propose that there are not separate senses at all, but a single perceptual system that directly perceives information that is fully specified in a 'global array' (*ibid.* p. 206, "spatiotemporal structures that extend across multiple forms of ambient energy").

Regardless of whether sensory perception is best understood in terms of supramodal or 'separable-but-linked' mechanisms, the overall impression from the studies reported above stresses perceptual interdependence rather than independence (i.e. no perceptual vacuum). Central to this interdependence are the intentions of the viewer that are influenced by task constraints (as was the case in the perception-action loop presented in Chapter 1, and as is the case in much of the remaining discussion).

2.2.2 Interacting visual systems

As with links in cross-modal perception, both unitary and 'separable-but-linked' mechanisms have been implicated in sensorimotor perception. In the visual domain, rather than a unitary perception-action visual system, the consensus of opinion favours a range of neuropsychological, neurophysiological and psychophysical evidence that suggests a 'separable-but-linked' relationship between vision-for-perception and vision-for-action via two broadly separate visual systems (see Creem and Proffitt, 2001a for a recent review). The key characteristics of the two visual systems (ventral and dorsal) are summarised in Table 2.2. While a direct route to action is catered for by visuomotor perception in the dorsal stream ('**separable**-but-linked'), it is notable that 'conscious' visual perception is not an entirely separate endeavour, but can inform and be informed by the simultaneous activities of the dorsal system ('separable-but-**linked**'). So much so in fact, that it can make sense to talk of the two systems functionally in terms of 'semantic' and 'pragmatic' systems, which are not devoted respecters of the anatomical separations of the more widely accepted 'what' and 'how' systems (e.g. Jeannerod, 1999).

Table 2.2 Key characteristics of the two visual systems

Characteristics	Ventral system	Dorsal system
Anatomical[1]	From primary visual cortex, terminating in inferior temporal cortex	From primary visual cortex, terminating in posterial parietal cortex
Physiological	Includes units that selectively process *invariant* aspects of even complex objects (e.g. faces[2] rather than elements) Key point is end-stage recognition	Includes object and motor-type units that selectively respond to spatial or shape elements relevant for visually controlled actions[3] Key point is visuomotor nature
Temporal[4]	Subjective report of stimulus change is slow, hence lasting representations.	Movement correction to stimulus change is immediate, hence online transformations
Frames of reference[5]	Units have stronger world-referenced modulation	Units have stronger body-referenced modulation
Developmental[6]	a) Velocity information is only perceived after 2 months[7] b) Newborns cannot perceptually distinguish (no dishabituation) different directions of motion[9] c) 6-month-olds fail to extrapolate object motion in preferential looking tasks[11]	a) Velocity information is used for action in newborns[8] b) Newborns can crudely direct arm movements to a moving toy[10] c) 6-month-olds predict linear object motion when reaching[12]
Functional	Damage to system impairs visual awareness (object discrimination and recognition) but not visually guided actions[13]. Key point- vision for perception, hence 'What' system[1, 14]	Damage to system impairs visually guided actions but not visual awareness [15]. Key point- vision for action, hence 'How' system[14] preferred over earlier 'Where' interpretation[1]

1) Ungerleiger & Mishkin, 1982; 2) Perrett, Mistlin & Chitty, 1987; 3) Murata, Gallese, Luppino, Kaseda & Sakata, 2000; 4) Castiello & Jeannerod, 1991; 5) Snyder, Grieve, Brotchie & Andersen, 1998; 6) As reviewed by van der Kamp & Savelsbergh, 2000; 7) Wattam-Bell, 1990; 8) Jouen, Lepecq, Gapenne and Berthenthal, 2000; 9) Wattam-Bell, 1996; 10) Von Hofsten, 1982; 11) Spelke, Katze, Purcell, Ehrlich & Breinlinger, 1994; 12) Von Hofsten, Vishton, Spelke, Feng & Roseander, 1998; 13) Goodale , Milner, Jacobson & Carey, 1991; 14) Jakobson, Archibald, Carey & Goodale 1991; 15) Goodale & Milner, 1992

Separable-but-linked visual systems

The most compelling evidence of two quasi-independent systems comes from a double dissociation of functional capabilities in patients with small lesions to either system (see "Functional" row in Table 2.2 above). However, it should be emphasised that the two systems share many connections, and cross talk between the two systems is extensive in an intact visual system (Milner and Goodale, 1995). This is especially so when semantic processing of an object is required (e.g. Humphreys, 2001; Creem and Proffitt, 2001a).

Despite this, by employing techniques that involve 'tricking' the visual system, it is possible to sever links between vision-for-perception and vision-for-action in visually intact participants.

To these ends, early studies on induced motion (e.g. Bridgeman, Kirch and Sperling, 1981) presented a fixed target and a background frame that was displaced to the left or right. The visual experience was of 'stroboscopic induced motion', whereby the fixed target appeared to jump in the opposite direction to the background frame. When target and frame disappeared and participants pointed to the 'last' target position, points were unaffected by the consciously experienced target jump (that is, points were accurately made to the veridical target position). Furthermore, when participants had no conscious experience of motion (they adjusted the real motion of a target into phase with the background), they nevertheless pointed in accord with the veridical last position of the target.

A range of studies using visual illusions report a similar phenomenon, where typically parameters of an action such as grasping (e.g. Haffenden and Goodale, 2000; Jackson and Shaw, 2000; Servos, Carnahan and Fedwick, 2000) and hand transport (e.g. Fischer, 2001) remain *unaffected* by the perceived visual illusion (e.g. a line appears to be longer than is veridical, or a disc appeared to have a larger diameter than is veridical).

Separable-but-*linked* visual systems

Some researchers however (e.g. Franz, Gegenfurtner, Bülthoff and Fahle, 2000; Haffenden and Goodale, 1998) have raised methodological doubts about certain illusory studies (notably a benchmark study by Aglioti, DeSouza and Goodale, 1995). Others have demonstrated that certain illusion induced differences between perception and action actually reflect two experimental conditions rather than two visual systems (Mon-Williams and Bull, 2000).

Indeed, it has been shown that with careful experimentation visual illusions *can* influence various parameters of action such as grasping (Daprati and Gentilucci, 1997; Franz et al.

2000; Vishton, Rea, Cutting and Nuñez, 1999; Brenner and Smeets, 1996; Haffenden and Goodale, 1998; Pavani, Boscagli, Benvenuti, Rabuffetti and Farnè, 1999, Haffenden and Goodale, 2000), reaching (Gentilucci, Benuzzi, Bertolani and Gangitano, 2001), movement times (Westwood, Dubrowski, Carnahan and Roy, 2000) pointing (van Donkelaar, 1999) and grip force (Jackson and Shaw, 2000). Although these illusory effects on action occur, the influence generally appears to be less pronounced than illusory effects on perception (although see Vishton et al. 1999).

Two recent studies by Sowden and Bruyn, (2001) and Sowden, Bruyn, Myers (2002) have avoided the controversy of illusory studies by using a change blindness paradigm. Rather than visual illusions that make two objects that are veridically identical lengths *appear* different (e.g. the Muller Lyer illusion), here two objects that actually *are* different lengths do not appear different owing to change blindness (until, that is, the change is finally detected). In Sowden and Bruyn's (2001) study, participants made open-loop reach-to-grasp movements to a bar stimulus presented on a monitor. Using a 'flicker' paradigm (a global screen flicker occurs as the second image replaces the first, thus masking the change), bars were presented in sequential pairs that could change in length by 1 cm. On trials before the change was detected, grip aperture was consistent. Once the change was detected (verbal report), the average modulation of grip aperture was 1.1 cm greater than before the change was detected. Sowden, Bruyn, Myers (2002) repeated the study with real three-dimensional bars, whereby participants reached for bars presented sequentially, using a rotating turntable. A blank display screen that separated the pairs of bars induced change blindness. A similar pattern of results was found. Thus action was only affected once a change had been consciously detected.

Overall, studies such as these do not support a simple dichotomy of function (vision-for-action and vision-for-perception) but rather suggest the functional interaction of ventral and dorsal streams.

2.3 Unitary perception-action perspectives (non-representational)

When cognition, perception and action are seen as emergent properties of multiple layers of interacting feedback loops (in which intention, attention and values all contribute), the 'outside-in approach' reveals itself to be oversimplistic and perhaps fundamentally misguiding. While careful experimental manipulations, developmental milestones or specific damage-induced brain defecits can reveal a severence of links between senses or between perception and action, there is nevertheless a danger of overlooking emergent global phenomena. The approaches discussed below have all opted for a holistic approach to studying the dynamic contingencies between brain, body and world. The general perspective of embodied cognition (see Chapter 1) underlies all of these approaches, and while there are undoubtedly differences of emphasis, all commit to explaining a unified brain-body system comprising of various sensory modalities and their respective sensorimotor systems.

The purpose of this section is not to review in any detail the evidence associated with the unitary approaches discussed, but rather to communicate the ideas involved, and in particular, point out the underlying similarities between these superficially different approaches. The first, and perhaps most elegant theory to be discussed, comes from O'Regan and Nöe (2001).

2.3.1 Sensorimotor contingencies

O'Regan and Nöe (2001) are not surprised that two relatively independent visual systems might subserve different capacities because they view vision as an activity that depends upon a broad range of relatively independent capacities (e.g. bodily movement and guidance, speech, rational thought). O'Regan and Nöe (2001) outline a sensorimotor theory of vision and visual consciousness, the underlying principles of which apply to all sensory modalities. They argue that experience within any modality exists only within the context of an acting organism and all of its available senses. Any experience associated with a particular modality (vision, audition, touch etc) will have its own specificities (owing to the nature of its particular sensors and sensorimotor contingencies), yet there will be interactions between these senses by virtue of systematic correlations and some common 'sensorimotor contingencies' (i.e. sensory changes produced by various motor actions and vice versa).

Talk of distinct yet interacting senses might suggest that this is a 'separable-but-linked' account of vision. However, O'Regan and Nöe (2001) do not appeal to sensory-modality-specific essences, mechanisms, nerve energies or pathways- what matters when distinguishing between the senses is the different things that we do when see or hear or touch etc. A sensory experience (whether visual or auditory etc) is constituted by its mode of environmental exploration. From this perspective, the principles or laws of sensorimotor contingency *unify* the sensory modalities that underlie perception and action.

Sensorimotor contingencies in the context of behavioural activity

As with interactive approaches to vision discussed in Chapter 1, vision can be appropriately described as an exploratory activity. O'Regan & Nöe (2001) emphasise the exploratory activity of vision and consequently place the burden of explanation on the activity itself, not on the internal representing of the world. Two studies reviewed by Järvilehto (1998a) shed some light on the importance of considering an entire behavioural activity (see Box 2.1).

It is generally accepted that visual perception can be modified by top-down influences. The rabbit-duck illustration routinely reproduced in Visual Perception textbooks is testament to this. The two studies reported in Box 2.1 suggest that more than mere perceptual modulation, efferent connections can influence the sensory organs themselves. What appears to be important is not some passive sensory transmission of environmental information, but how the system behaves as a whole within a behavioural activity (see later for similar arguments).

Box 2.1 An illustration of the importance a behavioural activity has for sensation

Astrand, Hamalainen, Alexandrov and Järvilehto (1986) studied the responses of cutaneous peripheral neural units (i.e. skin cells) while human subjects performed different tasks. Recorded via microelectrodes from the radial nerve at the wrist level, the responses of single mechanoreceptive units were found to change with the task given. When subjects attended to varying intensities of tactile pulses (that were applied to the receptive field of a single unit), certain response characteristics were found. The response characteristics of the very same unit *changed* when the task involved counting deviant tones in an auditory task- even though identical tactile pulses were applied. Järvilehto (1998 a) raised the possibility that these dynamic changes might reflect a general sensitisation of receptors while attending to different types of stimuli.

However, a study by Alexandrov, Grichenko, Shvyrkov, Järvilehto and Soininen (1986) suggests otherwise. Such changes appear to come about from the activity itself, that is, the whole behavioural situation. Thus in a food-acquisition task, when receptor level activity (of units located in the optic nerve prior to entering the lateral geniculate body) was recorded in a rabbit, the activity of the units covaried with certain phases of the rabbit's behaviour (e.g. activation covaried with the rabbit's approach to a food-release pedal or an automatic feeder). This covarying activation was reproduced when the trained rabbit performed the task with non-transparent cups that prevented the use of visual information. These effects were therefore not due to visual stimulation or visual attention. Furthermore the unit discharges were shown to reflect the activity of ganglion cells (and not of efferent fibres). The key point of these two studies is this- an important factor that influences sensation is the behavioural activity that the perceiver-actor is currently involved in. As was argued in Chapter 1, perception is not a passive process, but an activity. It would appear that the same applies to sensation itself[8].

Laws of sensorimotor contingency that govern visual exploration

Bearing in mind the importance of a currently exercised behavioural activity, we can turn to O'Regan & Nöe's (2001, p.4) central claim:

> "Vision is a mode of exploration of the world that is mediated by knowledge, on the part of the perceiver, of what we call sensorimotor contingencies".

According to the theory, there are two sets of laws that distinguish visual percepts from perception in other modalities.

[8] Järvilehto (1998 a, b, c, 1999, 2000) argues that receptors do not code environmental information and transmit it to the nervous system, but are instead connections that support dynamic organism-environment systems. Clark's (1998) response to Järvilehto (1998 a) is more liberal- sometimes (but not always) the senses engage in selective and minimal information transmission- not such that it is necessarily used to create a rich inner model of the environment, but the senses nevertheless support transmission.

1. *Visual Apparatus:* Visual exploration obeys certain laws of sensorimotor contingency that are determined by the *visual apparatus* itself (e.g. eye movements distort and shift retinal stimulation; eye blinks produce uniform retinal stimulation; forward or backward body movement produces an expanding or contracting flow pattern on the retina; sampling density varies from peripheral to central vision). These contingencies are unlike other senses, such as audition, which is affected by head movements for example, but not by eye blinks. Thus certain laws of sensorimotor contingency are specific to the *visual apparatus*, and these are in part responsible for the visual experience.
2. *Visual attributes:* Visual exploration obeys certain laws of sensorimotor contingency that are determined by the visual mode of sampling three-dimensional objects, and this mode reveals the *visual attributes* of objects (e.g. the retinal image only provides a view in front of an object, whereas moving around an object makes part of it appear and disappear; the size of an object's retinal projection depends on distance; an object's colour or brightness changes lawfully as the object, the light source or the observer move; surfaces of objects undergo perspective changes when they are shifted or tilted, or when we move in relation to them; there are laws of sensorimotor *invariance* associated with the properties of lines, curves and corners, such that they are neural-code independent[9]). These contingencies are unlike other senses, for example touch, which does not have a 'point of view' and does not change with lighting conditions. Thus certain laws of sensorimotor contingency are specific to the visual mode of exploration that reveals *visual attributes* of three-dimensional objects, and it is these contingencies that are in part responsible for the visual experience.

In addition to satisfying the condition of an animal exploring its environment in a way that is governed by the two main sets of sensorimotor contingencies (1 and 2 above), O'Regan & Nöe (2001) suggest that vision must also satisfy the condition of being 'tuned to' these laws of sensorimotor contingency. Unlike the Gibsonian 'attunement' or 'resonance', being 'tuned to' these laws simply means that the animal must be actively exercising its mastery over them. In this sense these are not given laws, but laws that must be mastered through doing. Through currently exercising a mastery of these laws, one is said to have a

[9] For example, moving the eyes along a straight line will stimulate the same photoreceptors at all points along the line (lines are 'self-similar under translation along their length'). This law of sensorimotor invariance is an intrinsic property of *lines*, and is therefore independent of any code used to represent them.

practical knowledge of them[10]. For example, because our brains are 'tuned' to certain potentialities, when seeing a bottle, we have knowledge (in our nervous systems) that if our eyes are moved upwards towards the neck of the bottle or downwards towards its base, sensory stimulation will change in a lawful and predictable manner. Similarly we have knowledge that rotating particular objects will make parts appear and disappear (e.g. the handle of a pitcher might disappear as the pitcher is rotated). O'Regan and Nöe, 2001, p.7, write,

> "... the visual quality of shape *is precisely* the set of all potential distortions that shape undergoes when it is moved relative to us, or when we move relative to it. Although this is an infinite set, the brain can abstract from this a series of laws, and it is this set of laws which codes shape".

That knowledge of these laws comes about through currently exercising a mastery over them is demonstrated by studies where participants wear inverting glasses. O'Regan & Nöe (2001) review several such studies, where glasses invert the retinal image such that the world appears upside-down and/or left-right inverted. They claim that the observer's brain registers the fact that the normal laws of visually determined sensorimotor contingencies are not being obeyed, and consequently the observer has the impression that something is wrong (a weaker sense of this will be familiar to anyone who has worn a new pair of glasses with a different prescription). The brain must adapt in order to establish a mastery over a new set of laws appropriate to the new visual world. Indeed, this is what happens, and after initial incapacitation, wearers of inverted glasses gradually become able to move around effectively such that after about two weeks the visual world appears 'normal' again (a similar process of adaptation occurs when the glasses are removed).

Interestingly, the process of adaptation is fragmented and task and context specific. For example, O'Regan & Nöe (2001) review Kohler's (1951) study, in which visual context dramatically affects the visual appearance of objects. A candle that appears upside down suddenly flips when lit (because flames must go upwards); a coffee cup that appears upside

[10] Indeed, a substantial claim of the theory is that visual awareness arises when a currently exercised mastery of these laws is integrated with separate capacities for thought and planning.

down suddenly flips when coffee is poured into it (because coffee must pour downwards); and an observer standing on the sidewalk correctly sees vehicles driving on the right (and hears them approaching from the correct direction), yet still reports that the number plates appear in mirror writing. This last observation is telling, and as O'Regan & Nöe (2001, p. 26) explain,

> "reading alphabetic characters involves a subspecies of behaviour connected with reading, judging laterality involves another, independent, subspecies of behaviour, namely reaching. An observer adapting to an inverted world will in the course of adaptation only be able to progressively probe subsets of the sensorimotor contingencies that characterize his or her new visual world, and so inconsistencies and contradictions may easily arise between 'islands' of visuo-motor behaviour".

This interpretation fits well with their explanation of the two visual systems discussed earlier, and is also compatible with the principles behind Brooks' specialised capability producing layers that are present in the subsumption architecture of his robots.

Laws of sensorimotor contingency and representation

For the laws of sensorimotor contingency, the brain can 'anticipate' possibilities for action (e.g. affordances), through being 'tuned' to certain *potentialities* (one has a latent and not activated practical knowledge of sensorimotor contingencies). These potentialities remain latent[11] until a potentiality-contingent activity is *currently being exercised.* For example, O'Regan and Nöe suggest that there are stored programs of movement that will only be activated when appropriate laws of sensorimotor contingency are currently being exercised. In other words, the active visual percepts/codes associated with a currently seen light switch *have the potential* to interact with the contingencies associated with aspects of the light switch's tactile attributes. These might be tactile location relative to the perceiver-actor, tactile shape, tactile size and tactile texture.

[11] A quote from Ryle (1949/1990, as quoted by O'Regan and Nöe, 2001, p. 13), concerning a person contemplating a thimble, helps to explain what is meant by this latent practical knowledge, "Knowing how thimbles look, he is ready to anticipate, though he need not actually anticipate, how it will look, if he approaches it, or moves away from it; and when, without having executed any such anticipations, he does approach it, or move away from it, it looks as he was prepared for it to look. When the actual glimpses of it that he gets are got according to the thimble recipe, they satisfy his acquired expectation-propensities; and this is his espysing the thimble."

This readiness to anticipate without actually anticipating may explain why O'Regan and Nöe claim their account is not representational. A latent practical knowledge of sensorimotor contingencies does not represent anything precisely because it is latent. When this practical knowledge is actualised through doing, there is similarly no need say it represents anything, because whatever might be 'represented' it already being done.

The necessity for knowledge of the laws of sensorimotor contingency that comes about through a currently exercised mastery over them is also central to the Enactive Approach (which, incidentally, O'Regan & Nöe, 2001 credit as an inspiration for their own theory). As is suggested by inverted glasses studies, a world is not simply re-presented as given, but in the words of the Enactive Approach, must be 'enacted' or 'brought forth'. Similarly, knowledge of sensorimotor contingencies comes about through doing and vice-versa, hence Maturana & Varela's (1987, p. 27) profound claim that "All doing is knowing and all knowing is doing".

2.3.2 The Enactive Approach

Meaning that is meaningless without the context of a history of lived interactions between an agent and its environmental niche (see discussion of derived intentionality in Chapter 1) is implicit in Varela, Thompson and Rosch's (1991) 'Enactive Approach'. Their approach explicitly rejects representations, arguing instead that the world and the perceiver come to *mutually* specify each other over time. Cognition does not recover (an objectivist view) or project (a solipsist view) a world, but 'enacts', or 'brings forth a world' through a history of structural couplings.

Core ideas of the Enactive Approach

The history of structural changes that unfolds in a living being (thus changing its initial structure) comes about from its interactions with the environment. These interactions can be explained in terms of perturbations of the environment that *trigger* (rather than determine, select, instruct or specify) changes in the living being that are actually *determined* by the structure of the living being. The same applies to the environment (or indeed any system); perturbations of the living being *trigger* changes in the environment that are actually *determined* by the structure of the environment.

A living being and its environment are seen as two operationally distinct unities[12] (c.f. the operational closure of the perception-action loop described the Introduction). There is however, a necessary structural congruence between them that arises from a history of recurrent interactions (during which they both undergo a history of structural changes). The initial structure of a living being conditions the course of its interactions with the environment and also constrains the possible changes to its structure that the environment may trigger in it (again, this is implicit in the perception-action loop).

There are four domains or classes of structural change: changes of state (all changes a unity can undergo without changing its organisation); destructive changes (all changes a unity can undergo with a loss of organisation); perturbations (all interactions that trigger changes of state); and destructive interactions (all those perturbations that trigger a destructive change). For example, Maturana & Varela (1987) consider an instance of a destructive interaction between a person and a bullet. The perturbation of the bullet triggers in the person a destructive change (the loss of organisation resulting in death) that is determined by the person's structure. For a vampire however, the bullet merely triggers non-fatal changes in state that are determined by its structure. An encounter with a wooden stake through the heart however, would be a destructive interaction for the vampire.

This ongoing process of mutual sources of perturbations triggering (but not determining) changes of structure is called 'structural coupling'[13], and 'enaction' describes this process of 'bringing forth of a world' through its history of structural couplings.

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[12] An alternative view by Järvilehto (1994,1998 a, b and c) proposes that there is a *single* organism-environment unity. Organism and environment are functionally inseparable and there is no transfer process from the environment into the organism because there are not two systems to transfer between.

[13] Structural couplings are conceptually similar to O'Regan and Nöe's sensorimotor contingencies. The second set of laws (that are related to visual attributes of the objects) could be said to trigger changes in structure that are determined by the first set of laws (that are related to the visual apparatus itself).

Varela and colleagues offer many insightful examples of enactive cognition that essentially reflect the process of structural coupling (including Genghis). However, they use colour vision as *the* case study of enactive cognition (in particular, see Thompson, Palacios and Varela, 1992). Perturbations of light are said to merely trigger states of neuronal activity that are determined by a person's individual structure and not by features of the perturbations. Consequently, our naming of colours correlate with states of neuronal activity, but not with the wavelengths of perturbations of light. Colours, they argue, are neither 'out there' in the world independent of perceptual and cognitive capacities, and nor are they 'in here' independent of our biology and culture.

This fits well with the views of Brooks & Stein, (1993), who invite us to consider a neuron that fires (or a particular wire that carries a positive voltage) when something red is seen. The neuron or wire could easily be misunderstood as 'representing' the presence of something red to the agent, but for the agent (i.e. its experience) the neuron or wire actually *is* the presence of something red. In the language of the enactive approach, the colour red is enacted - it does not exist independently "out there" and so cannot be re-presented "in here". Maturana & Varela (1987) extend this notion to all dimensions of the visual experience (movement, texture, form etc.) and to all perceptual modalities.

The Enactive Approach and Evolutionary Theory

A major objection the Enactive Approach has to representationalism is its assumption that representations recover a 'pregiven' world. Varela et. al (1991) (and previously, Maturana & Varela, 1987) parallel their approach with increasingly popular views of "natural drift" in evolutionary theory; views that challenge the adaptationist emphasis on optimisation in "natural selection" that is so central to neo-Darwinist views. In short, adaptationists view evolution as a process by which organisms progressively adapt to a pregiven world, optimising their use of it through the mechanism of natural selection.

Varela et.al (1991) favour alternative 'natural drift' accounts whereby evolution is seen as a process of structural drift that undergoes phylogenic selection. There is no optimisation of the use of a pregiven environment, only the conservation of adaptation and autopoiesis. Autopoiesis is another central theme of Maturana & Varela (1987) that describes the process of self-making (i.e. persisting as an autonomous being). Of more relevance for present purposes however, is the notion that the adaptation of a living being to its environment is a necessary consequence of its structural coupling with that environment.

Organism and environment remain in a continuous structural coupling (the drift occurring in both unities such that there is 'mutual specification' or 'codetermination'). Varela et.al (1991) suggest that this mutual specification is particularly evident in apparent cases of coevolution such as the ultraviolet reflectance of flowers coevolving with the ultraviolet sensitive trichromatic vision of bees. Consequently the evolutionary process is seen as proscriptive not prescriptive, and natural drift describes the taking of suboptimal rather than optimal solutions. The human visual system for example, appears to have taken a suboptimal solution to vision, in that it is wired up back to front. These solutions are nevertheless satisfactory, as they allow the organism to maintain its integrity to persist. In this way selection is seen as a "broad survival filter" (Varela et. al, 1991, p.196).

Enaction and representation

The Enactive Approach appears to offer a more holistic understanding of cognitive processes than most representationalist accounts. The rejection of representations, however, appears to be based on dated notions of representation. Consequently, it can be argued that the 'bringing forth of a world' is not necessarily incompatible with refined notions of representation (see Chapter 1). The idea of structural coupling is intuitive, yet it does not appear to exclude subsymbolic connectionist representations. Even the simplest forms of connectionism, for example content addressable memory, appear to undergo a form of structural coupling. An 'environmental' input (e.g. a couple of letters), merely triggers changes in state. It is the initial structure of the network that determines what these changes will be. The settled state of the network (e.g. a word), *if it is not then reset to default values*, will constrain the course of structural changes that a consequent input may trigger. Furthermore, there is no reason in principle (or indeed practice) why an appropriately organised ANN should not connect its output layer to its input layer, thus (perhaps more legitimately) constraining the course of future structural changes. This first-order structural coupling, it seems, is not at odds with a representational stance.

What of second-order structural couplings, whereby animal and environment *mutually* specify each other? Clark (1997) dismissed the Enactive Approach on the basis of the problematic idea that objects are not independent of mind. The Enactive Approach need not be interpreted as saying this however. It does not appear to say that objects do not *exist* independently of mind, just that properties of objects are not independent of mind (in the same sense that a Gibsonian affordance of an object can only be considered relative to the perceiving animal). Indeed, Varela et. al (1991) endorse the theory of affordances, but not the 'pregiven' nature of information in the optic array. As Varela et. al (1991, p.167) explain,

> " ...how are we to specify what counts as a surface? How are we to specify its edges, boundaries, texture, and orientation, if not in relation to some perceiver for whom these distinctions are relevant?"

In this sense, information does not come 'ready-made' in *the* world, but is 'enacted' in *a* world. This view does not challenge representationalism, for as we have seen in the Introduction, action-oriented representations embrace this very idea. Furthermore, as was argued in Chapter 1, a sensible treatment of intentionality (when applied to representational functions) rejects 'original intentionality' (some 'truth' about *the* world) and accepts a 'derived intentionality' that comes about from a history of interactions between an animal and *its* world. This is in keeping with the Enactive Approach's rejection of a 'pregiven world'.

What is more, saying that animal and environment are two operationally distinct unities that are necessarily structurally coupled does not imply that objects do not exist independently of mind. A simple example Maturana and Varela (1987, p.99) offer is the history of structural coupling between lineages of automobiles and cities,

> "...there are dramatic changes on both sides, which have taken place in each one as an expression of its own structural dynamics under selective interactions with the other."

A car does not cease to exist if taken out of a city, yet aspects of its structure reflect the fact that it emerged from a city environment. It is however, unlikely that a car would exist if its lineage came from a desert village with wood as the only raw material, and it is unlikely that a city like Plymouth would exist as we know it (with its roads, car parks and penchant for roundabouts) if cars had not been invented. Similarly an object (e.g. a Granny Smith apple) would not cease to exist if all perceiving animals disappeared; yet aspects of its structure reflect the fact that it emerged from a particular environment (such as one inhabited by humans with pesticides).

Second-order structural couplings seen in this way simply reflect the process by which, over the course of time (whether this is over an individual's or evolutionary timescale), the world shapes its animals, and animals shape their world. Representationalism can benefit from this view by adopting 'natural drift' over 'natural selection' as its preferred mechanism for development. Rather than viewing organisms as progressively adapting to a pregiven world (optimising their use of it through natural selection), the adaptation of an organism can be seen as necessary consequence of a lived history of structural couplings. As Varela et. al (1991, p.205) explain,

> "If this coupling were to be optimal, the interactions of the system would have to be (more or less) prescribed. For coupling to be viable, however, the perceptually guided action of the system must simply facilitate the continuing integrity of the system (ontogeny) and/or its lineage (phylogeny)."

By allowing this kind of 'viability function', the emphasis on optimal representations is removed and we can avoid the temptation of seeing the brain as encoding what Clark (1997) calls "fully programmed specifications of development or action".

Another unified theory of cognition that appeals to evolutionary theory comes from Edelman (1978, 1987, 1992). Although appealing to the mechanisms of natural and somatic selection, Edelman's theory is actually a closely related effort to that of the Enactive Approach.

2.3.3 The theory of neuronal group selection

Edelman's 'theory of neuronal group selection'[14] (TNGS) is again an embodied account of cognition. As with the knowledge of sensorimotor contingencies and the Enactive Approach, cognition comes about thanks to a *history* of interactions with the world. The world is not seen as 'pregiven', with objects or categories coming ready-made in the world (unlike, say, the Gibsonian 'information in the optic array'). Instead, the brain must selectively create objects and categories through a history of embodied experience ("The mind does not mirror nature", Edelman, 1992, p.234). Similarly, the brain is not 'pregiven' in that it is not hard-wired with pre-determined information-specific networks (although, of course, the genetic code ensures the gross architecture of the brain).

As mentioned above, although Edelman's account depends on the mechanisms of selection (natural and somatic), it does not appear to be at odds with a 'natural drift account'[15]. Selection that is viable rather than optimising seems to fit Edelman's approach well, for he sees 'degenerative' neuronal groups as the basis for selective processes. Their functional degeneracy (whereby different neuronal groups provide different ways of doing the same thing more or less well) ensures that there is no 'optimal' solution to a particular function. Several different neuronal configurations for example can carry out the same function, and a single neuronal group can contribute to multiple functional relations. It is no surprise then, that Edelman (1992) also rejects cognitivism and representationalism (adding them to

[14] Edelman's Neural Darwinism has not received overwhelming support, largely because many find it unreadable. Indeed, Edelman (1992) recounts Francis Crick's suggestion that it should be called 'neural Edelmanism'. There are however, accounts of cognition that are closer to Darwinism proper (e.g. Calvin, 1996).

[15] Indeed, Varela et al (1991, p.200) argue that some selectionist theorists (and Edelman in particular) do lean towards a natural drift view of evolution.

'a graveyard of isms'), and claims that the brain does not process information[16] (again, as with the Enactive Approach, the brunt of this criticism is directed at the easy target of the 'brain as computer' metaphor). Instead, the brain is seen as a selective rather than instructive system that is essentially a correlator (especially the cerebral cortex), adapting to the environment through a kind of 'neural Darwinism'.

Core ideas of the TNGS

Edelman proposes that stimuli (that result from the relationship between the environment itself and previous actions of the agent, such as head and body movements, saccades etc) select among (i.e. enhance or suppress the activation of) previously formed states of the nervous system. These states are described as degenerative neuronal groups (closely connected collections of cells), which contribute to more complex nervous system states such as maps, classification couples and global mappings (see below). Recognition and categorisation occur only as a result of this selection. In terms of the Enactive Approach, it could be argued that environmental stimuli trigger changes in the system (i.e. selection), that are actually determined by the current structure of the system (i.e. pre-existing neuronal groups). That these neuronal groups are pre-existing does not mean that they are 'pregiven' in the sense meant by the Enactive Approach. Particular neuronal groups do not necessarily come with a 'pregiven' function, but compete for one. This is demonstrated by cases of neural plasticity[17], such as the recruitment of the auditory cortex for visual processing reported earlier in Table 2.1.

Three steps to ontogenic brain development

Edelman argues that there are three broadly independent steps in the development of a brain:

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[16] Some commentators have argued that Edelman's theory does concern information-processing, and that Edelman bases his rejections on misunderstood, oversimplified and outdated accounts of information-processing (e.g. Dennett, 1995, Johnson, 1992). As with representations, the debate has more to do with stereotypical prejudices and terminology than it has to do with underlying ideas.

[17] Edelman (1992) offers as an example the plasticity a monkey's somatosensory cerebral cortex. When nerves mediating finger touch are severed, the map boundaries subserving touch rapidly change, which Edelman takes to be the selection among groups competing within a map.

1. *Selection of neuronal groups:* A primary repertoire of neuronal groups arises epigenetically from several levels of somatic selective processes (e.g. various mechanical, chemical and molecular events that bring about cell divisions, connections and death). These processes are merely constrained (not determined) by the genetic code; hence no two individuals will have identical wiring.
2. *Selection of degenerative functions:* A secondary repertoire of neuronal groups arises from the selection of *variant* functional circuits. This essentially involves the selection of neuronal groups for degenerative functions through behavioural experience. Neuronal groups are the units of selection (no individual neuron is selected), and those groups that happen to fit a stimulus better than others respond more strongly and are selected by strengthening their synaptic connections (while others are weakened). The next time a similar stimulus is sensed, the selected groups will respond to it more strongly than others.
3. *Selective formation and coordination of maps:* Finally, a broader functional repertoire emerges from collections of neuronal groups that are called maps or mappings. Edelman (1992) describes maps as follows:

   > "maps relate points on the two-dimensional receptor sheets of the body (e.g. the skin or the retina of the eye) to corresponding points on the sheets making up the brain".

   For example, a frogs' visual system includes a map of visual space on the retina that is mapped in a definite way to particular regions of the frog's optic tectum, such that stimulation of a specific point on the retina will lead to the stimulation of neurons in a 'place dependent' region of the optic tectum. A 'local map' consists of several neuronal groups that are functionally related. When two local maps 'reentrantly' connect (by massively parallel and reciprocal connections), they constitute what is called a 'classification couple'. When multiple local maps connect they form higher-order structures called 'global mappings'.

Reentrant signals, classification couples, global mappings and values

Reentry: Primary and secondary repertoires provide basic functionality, but for an organ that is as adaptive as the brain, new functions must be generated. In order to account for multifunctional neuronal assemblies (rather than simple fixed-wire pathways that are sufficient for the robotic automaton Genghis, say), independent brain areas subserving different functions must be coordinated. Edelman invokes his principle of 'reentry'[18] for this purpose. Massively parallel and reciprocal connections between maps (maps formed by primary and secondary repertoires) allow for real time reentrant signalling. Neuronal

[18] Franklin (1995) suggests that Edelman's reentrant signalling is essentially equivalent to feedback in recurrent connectionist networks.

groups selected in a local map can select other groups in other local maps via these reentrant connections. Reentrant signalling and strengthening of connections therefore correlates and coordinates a variety of functions specific to local but distributed maps.

Classification couples: A classification couple is a minimal unit of reentry, where two functionally different maps are reentrantly connected. Each map independently receives signals from other maps or from the world (e.g. one map might receive visual inputs, and the other map, tactile inputs), and real time reentrant signalling connects certain active areas of one map to certain active areas of the other map. Synapses within groups in each map (and in their connections to reentrant fibres) are strengthened or weakened.

Global mappings: When multiple maps are reentrantly connected they form 'global mappings' that yield the global functions deemed necessary for adaptation and survival (e.g. categorization, memory and learning). Notably, these global mappings connect the selectional events of local maps to motor and sensory areas. Global mappings couple the outputs of multiple motor and sensory reentrant local maps, and they can interact with non-mapped parts of the brain (e.g. specialised structures such as the hippocampus and the cerebellum that serve as value systems). Learning is said to result from the operation of neural linkages between global mappings and the brain's value centres.

Value criteria: Values are crucial because they provide some constraints (*not specifications*) on what kinds of sensations or behaviours are appropriate for the animal. Edelman (1992) argues that the bases for value systems in animals are already set by evolutionary selection and are exhibited by those brain regions that regulate bodily functions (e.g. heartbeat, breathing, sexual responses, feeding responses, endocrine functions, autonomic responses). For example, the behaviours of Darwin III (Edelman's simulated autonomous agent that embodies the principles of TNGS) are constrained by value (e.g. light has more value than dark, light and stimulation have more value at the centre of vision than at the periphery). In a similar fashion, values constrain the behaviours of Brook's Genghis and Grand's Creatures.

Implications of the TNGS

Global mappings allow 'objects' in the world to come into existence as objects- (that can be recognised, categorised, memorised and so on). Global mappings construct our objects and events in accordance with our embodied experience of the world. There is no 'object recognition centre' or 'apple neuron'; objects and events are created through the coordination and correlation of various functionally distinct brain areas (crucial to which are sensory and motor areas).

Edelman (1992) argues that the three basic tenets of TNGS are sufficient to account for all cognitive functionality (whether it be recognition, categorisation, learning, memory, or even consciousness). Concepts for example, come about through re-combinations of different kinds of global mappings. Once again, there is no need for specialised 'concept neurones' (unlike Grand, 2000, for example, whose Creatures formed 'concept neurones'); or for some homunculus to interpret them.

Global mappings have all the qualities of a dynamic loop similar to the one presented in Chapter 1 (although we now can add a value system to the loop). Ludwig (1995, p.4) offers a useful description of global mappings in this light, whereby a global mapping,

> "...is continuously forced to reorganize by the flow of signals from many sources in- and outside the brain. Moreover, the organism is permanently endeavoured to seek new information or even new inspections of interesting objects or events. The mapping of perceptual categories onto behavioural categories in continuous time is the necessary basis for being in operational closure with the world."

Neural Darwinism and representation

Could a representational gloss do justice to this dynamic loop that continuously matches perception with action across the whole body? Edelman's (1992, p. 158) suggestion is appealing; it is we, and not our brains, that "represent" the world.

2.4 Unitary perception-action perspectives (representational)

The final two unitary approaches to be discussed are representational accounts of perception and action planning. Both accounts propose a common representational domain that does not respect the conventional boundaries between perception and action planning. That is, perceiving and anticipating are treated as equivalent both in terms of function and neural codes. Both are embodied accounts of cognition whose proposed abstract codes develop through worldly and bodily experience. The first is a developmental account of action control (Elsner and Hommel, 2001), and the second is a wider Theory of Event Coding (TEC), upon which the developmental model is based (Hommel, Müsseler, Aschersleben and Prinz, 2001).

2.4.1 The emergence of action control

Appropriately enough, TEC assumes that perception and action are intimately linked (indeed, they are seen as indistinguishable) via abstract (but not arbitrary) common codes. Before discussing the core assumptions of TEC (which revolve around the common coding of events), the following presents the proposed developmental basis for these event codes. Elsner and Hommel (2001) present the developmental foundations of TEC in a two-stage model of the emergence of action control (see Figure 2.1). This model incorporates all perceptual modalities and deals with the development of voluntary action control.

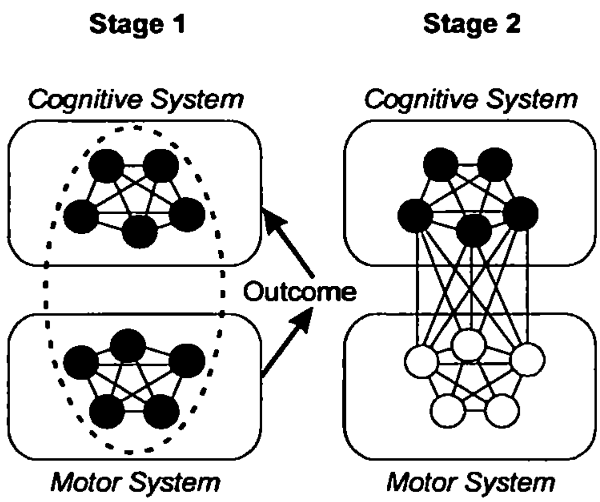

Figure 2.1 The emergence of action control (from Elsner and Hommel, 2001). At Stage 1, the motor pattern producing a particular effect is automatically integrated with the cognitive codes representing this effect. At Stage 2, the motor pattern is intentionally executed (white units) by activating the cognitive codes that represent its expected effect.

Prinz (1990, 1997) has presented similar ideas, which like TEC, share strong similarities to James' (1890) ideomotor theory and ideas on action representation expressed by Lotze (1852) and Harleß (1861).

Hommel (1997) suggests that the major difference lies in the scope of a movement effect. For Lotze, Harleß and James, a movement effect was limited to movement-produced sensory feedback (i.e. intrinsic feedback). For the Prinz and Hommel camp, a movement effect is far broader, in that the majority of action goals refer to extrinsic feedback, such as switching on a light, or stepping on a car's brakes (this is discussed in more detail later).

Stage 1: the formation of cognitive codes

The first stage of Elsner and Hommel's (2001) model concerns the acquisition of contingencies between movements and the effects that movements have on objects or events in the world. Hommel (1997) and Elsner and Hommel (2001) consider a newborn infant who initially must make *involuntary* actions[19] before it can logically perform a voluntary action. They argue that the voluntary control of action must develop from a history of perceived interactions, such that the effects of actions can be anticipated prior their production.

For example, a motor pattern is randomly generated (see the lower pattern of activated units in the motor system, Fig 2.1) and an action is executed (cf. 'motor babbling', Bullock and Grossberg, 1989). On occasion an executed action (e.g. a flailing arm movement) will lead to specific changes in the relationship between the infant and its environment (e.g. the hand comes into contact with a beaker, the beaker falls to the floor). These changes are perceived (e.g. sensory information is coded, such as the feel of the hand-beaker contact, the visual features of the hand-beaker contact, the sight of the beaker falling, the sound it makes crashing to the floor, etc.) and these changes are registered as more abstract cognitive codes (see upper pattern of activated units in the cognitive system, Figure 2.1).

[19] In reviewing the work of Lotze and Harleß, Hommel (1997) suggests that an involuntary action may be produced by external factors (e.g. stimuli directing direct, inbuilt sensorimotor connections), or internal factors (e.g. emotions or a curiosity drive). Nevertheless the actions will be random and erratic. This comes close to acknowledging that inbuilt values may constrain actions, which as we have seen, Edelman and others consider essential. However, value criteria are not mentioned in Elsner and Hommel's (2001) two-stage model or TEC, and it is unclear whether they have been overlooked, implicitly assumed, or are not considered important.

As the activated sensory and motor patterns are temporally overlapping they become integrated such that on a later occasion activation of one pattern will lead to automatic (partial) activation of the other[20].

Stage 2: the selection of an action

The second stage of the model concerns the goal-directed recruitment or selection of movements. Movements are selected by activating the 'effect code' that represents the desired goal (e.g. the code of a perceivable effect that has previously been associated with a motor pattern; such as the code for the sound of a beaker crashing to the floor). In activating this effect code, the associated motor patterns will be activated to some degree. Thus goal-directed movements are selected through activating the codes of their consequences (hence 'effect' codes), or put another way, the effects movements have on the world (e.g. a beaker that crashes to the floor) are *anticipated*. The actual spreading of activation from the effect codes to response codes is automatic and hence independent of any specific intention to act (cf. the APH), although this does not exclude the potential for additional intentional processes to control the selection of motor patterns. Any number feature-effect codes for a particular event, are represented by integrated structures that Hommel (1997, p.287-288) calls 'action concepts',

> "...both to express the different janus-faced functions they serve and to emphasise that they may comprise sensory and motor as well as more abstract information, such as the meaning of a movement forming a gesture or a symbolic act".

Behavioural evidence supporting the two-stage model

Elsner and Hommel (2001) tested their two-stage model in a small series of studies. Experiment 1a consisted of an acquisition phase and a test phase (corresponding to each stage of the model).

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[20] Elsner and Hommel (2001, p.230) claim that the *sensory* and motor patterns become integrated. Whether they really do mean sensory (rather than cognitive) deserves some attention, and this is discussed in section 2.3.5.

1. *Acquisition phase:* On each trial (200 trials) 24 participants responded randomly with a left or right key press to a white rectangle that appeared on the screen. An auditory tone (which participants were instructed to ignore) was presented 50 ms after the onset of each key press response. For 12 participants the left key triggered a low tone and the right key triggered a high tone (Response-Effect Mapping A). The other 12 participants received the opposite key-tone mapping (R-E Mapping B).
2. *Test phase:* The imperative stimulus was now a tone (high or low). Participants were pseudorandomly split into two groups (12 in each group), such that each group had 6 participants from each R-E mapping. As in the acquisition phase, responses triggered a tone contingent on the R-E mapping.
   a. *Non-Reversal group:* Participants had to respond to tones in accordance with their R-E Mapping. For example, those participants in R-E Mapping A (left response / low tone, right response / high tone) were instructed to respond with a left response to low tones and with a right response to high tones.
   b. *Reversal group:* Participants had to respond to tones in disagreement with their R-E Mapping. For example, those participants in R-E Mapping A (left response / low tone, right response / high tone) were instructed to respond with a right response to low tones and with a left response to high tones.

The results revealed that those participants in the non-reversal group responded more quickly than those in the reversal group. This data was interpreted as evidence that perceiving several co-occurrences of a self-produced movement (e.g. a certain key press) and a movement-contingent sensory effect (e.g. a certain tone) leads to the automatic association of the motor code representing the movement and the cognitive code representing the effect (despite this effect being task-irrelevant). Furthermore these associations were bi-directional, such that perceiving an event (e.g. a certain tone) automatically primed the associated action (e.g. a certain key press).

Variations on this experiment were run; all of which supported the two-stage model. For example, Experiment 1b revealed that acquired R-E associations were robust and resistant to extinction (removing the effect tone from the test phase did not change the pattern of results). In Experiments 2-4, when the test phase was free-choice rather than forced-choice (i.e. when participants were allowed to choose a response upon hearing a tone), they showed a bias for responding to the tone with the key that had previously (in the acquisition phase) produced that same tone. By introducing a third tone that enabled a 'go-no-go' design, Experiment 3 showed that this response bias increased when possible premature response selection was prevented (i.e choosing a response before the tone appeared). Furthermore, in an attempt to rule out possible strategic response-decision processes in the test phase (i.e. being consciously aware of the R-E Mapping, and trying to respond accordingly), participants in Experiment 4 had to count backwards during the test phase. The response bias was nevertheless still present.

2.4.2 The common coding account of TEC

Having presented the developmental model for action control, we can now examine the wider theory on which it is based, namely, TEC. TEC holds four core assumptions (as does the two-stage model) concerning its 'common codes' (these assumptions are shown in Figure 2.2 below).

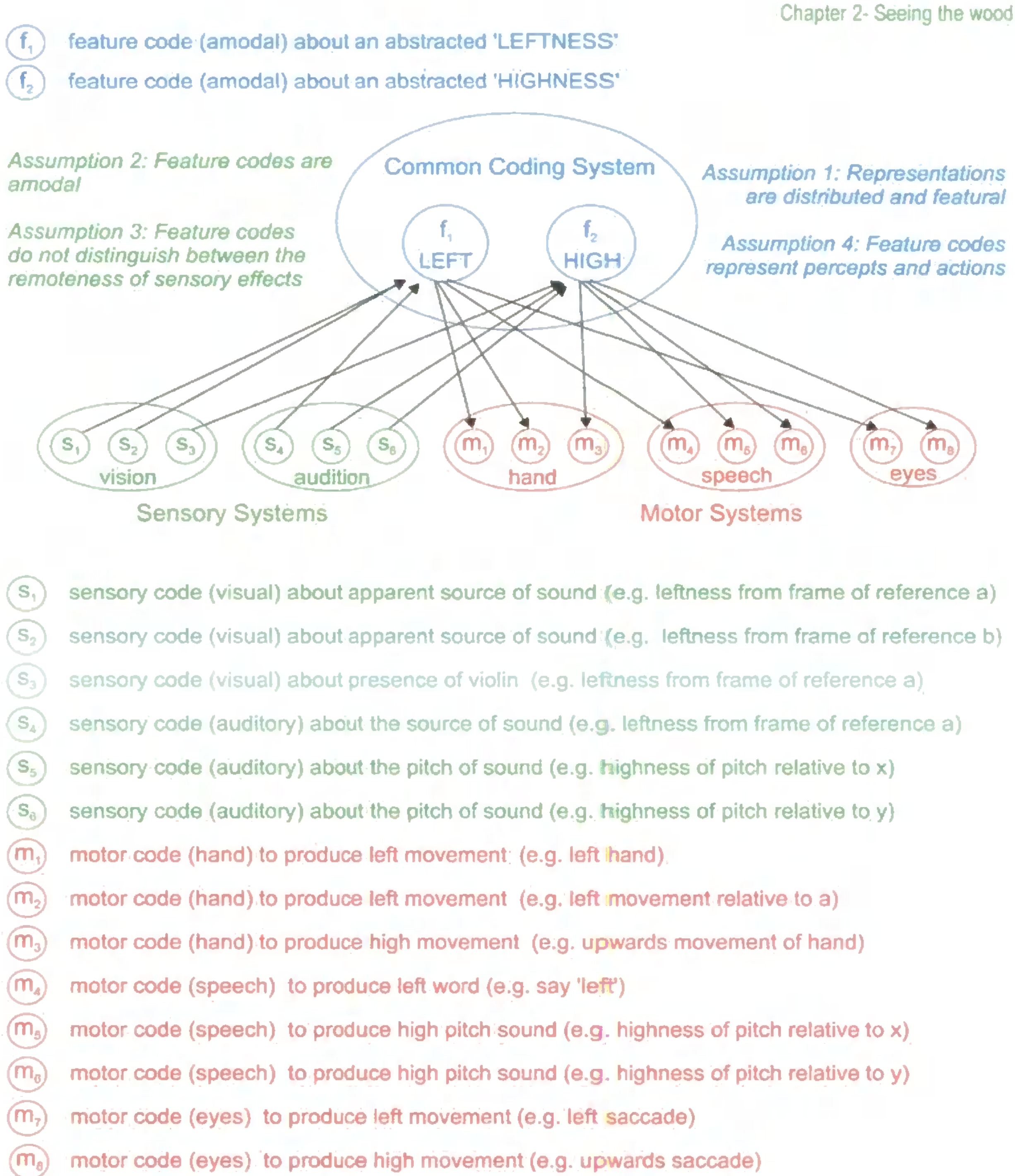


Figure 2.2 Adapted from Hommel et al. (2001). Feature coding according to TEC: In the example, the event is a violin playing a musical note. Sensory incoming information from two different sensory systems (s_1, s_2, s_3, and s_4, s_5, s_5, respectively) converges on two abstract feature codes (f_1 and f_2) in a common-coding system, which again spread their activation to codes belonging to three different motor systems (m_1, m_2, m_3; m_4, m_5, m_6, and m_7, m_8, respectively). Sensory and motor codes refer to proximal information, feature codes in the common-coding system refer to distal information. The four assumptions are elaborated in the text.

1. *Assumption 1 (featural representations):* TEC assumes that actions are represented in a distributed fashion in terms of their features (e.g. see description of featural representations in Chapter 1). Action representations comprise of integrated bundles of feature codes. Activating just a few feature codes belonging to an action representation will tend to activate the integrated whole (including its motor part). Consequently, one does not need to anticipate all the effects of an action to recruit the corresponding movement. This assumption can be seen visually in Figure 2.3.

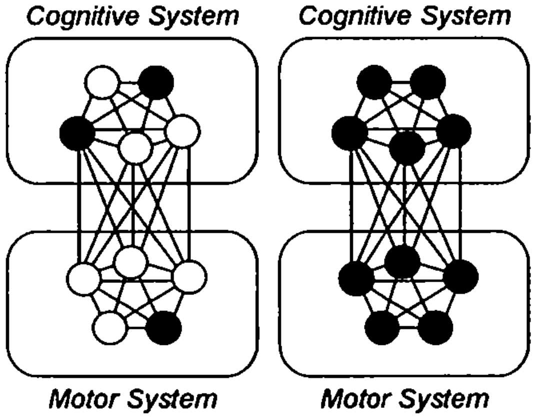


Figure 2.3 An illustration of TEC's assumption 1. White units are not activated. Activating just two feature codes (see upper left section) in an action representation may lead to partial activation of a motor pattern (see lower left section). However, because these two feature codes are merely part of an integrated whole, their activation spreads and the whole action representation including its motor part becomes activated (see right section).

Nevertheless, the more effects that are anticipated (i.e. the more feature-effect codes that are initially activated), the greater the level of activation will be on the motor part (*and this in turn increases the likelihood of selecting this action*). Thus there is a bi-directional influence of activation (cognitive -> motor; motor -> cognitive).

A notable property of distributed featural representations is that a single feature can play a part in (i.e. become integrated with) any number of other representations (but not at the same time, as discussed later). In this sense (Sense 1) TEC's feature codes are 'common codes' (in that they can be common to many different representations).

2. *Assumption 2 (feature codes are amodal):* TEC assumes that there is no difference between movement effects that are derived from different sensory modalities. However, it is acknowledged that during certain learning or action contexts, an agent may rely more heavily on information from one modality than from another. For example, kinaesthetic and tactile information may be especially useful for guiding hand movements, whereas visual information may especially useful for controlling eye movements (as was seen earlier in the cross-modal attention studies reported in section 2.2.1). In this sense also (Sense 2), TEC's feature codes are 'common codes' (in that they are common to all sensory modalities).

3. *Assumption 3 (feature codes do not distinguish between movement effects of differing remoteness):* TEC assumes that movement effects are coded irrespective of whether they derive from proximal sensation (e.g. the proprioceptive feeling of the arm moving towards a light switch), or distal consequences (e.g. the visual sensation of a light going on). This seems straightforward enough, but TEC is inconsistent on this assumption, and there are deeper underlying issues at stake (see section 2.3.5). Nevertheless, in this sense also (Sense 3), TEC's feature codes are 'common codes' (in that they are common to both proximal and distal effects).

4. *Assumption 4 (feature codes are both perceptual and anticipatory codes):* TEC assumes that the very same feature code will be activated when an agent forms an intention to produce a certain action effect (i.e. endogenous activation owing to the *anticipation* of an action effect) and when s/he perceives an event that resembles a known action effect (i.e. exogenous activation owing to the *perception* of an event). Thus an intention to reach with a left hand towards an object (e.g. LEFT feature code) activates the very same code that is involved in perceiving that object (e.g. it is located on the left, hence LEFT feature code). Thus perception and action planning (anticipation) are considered to be functionally equivalent, as they both internally represent the interactions between external events and the agent (for similar ideas see Prinz, 1990, 1997). It is in this sense (Sense 4) that TEC refers to its feature codes as 'common codes' (in that they are common to both perception and action planning)[21].

The event coding of TEC

It is often assumed that some sort of control mechanism is needed to ensure that we are not stimulus driven agents. If, as TEC suggests, motor patterns are automatically activated through perception and/or anticipation, then some sort of mechanism is needed to stop actions from running wild[22]. Furthermore, subsymbolic representations (such as featural representations) require integrating so as to ensure that features belonging together (both spatially and temporally) are represented as such. In line with these considerations, TEC argues that an activated and integrated collection of feature codes constitutes an event code that has temporal and conceptual coherence.

[21] For a recent ANN architecture that has (independently) implemented a very similar idea of sensorimotor anticipation that is constrained by intentions and goals, see Gross, Heinze, Seiler and Stephan (1999).

[22] As seen for example in cases of alien hand syndrome, where one hand operates everyday action routines whilst being completely resistant to conscious control (e.g. Parkin, 1996).

This event code (c.f. 'action concept') is the core theoretical construct of TEC, and it is the product of feature codes that have been bound together (see Figure 2.4).

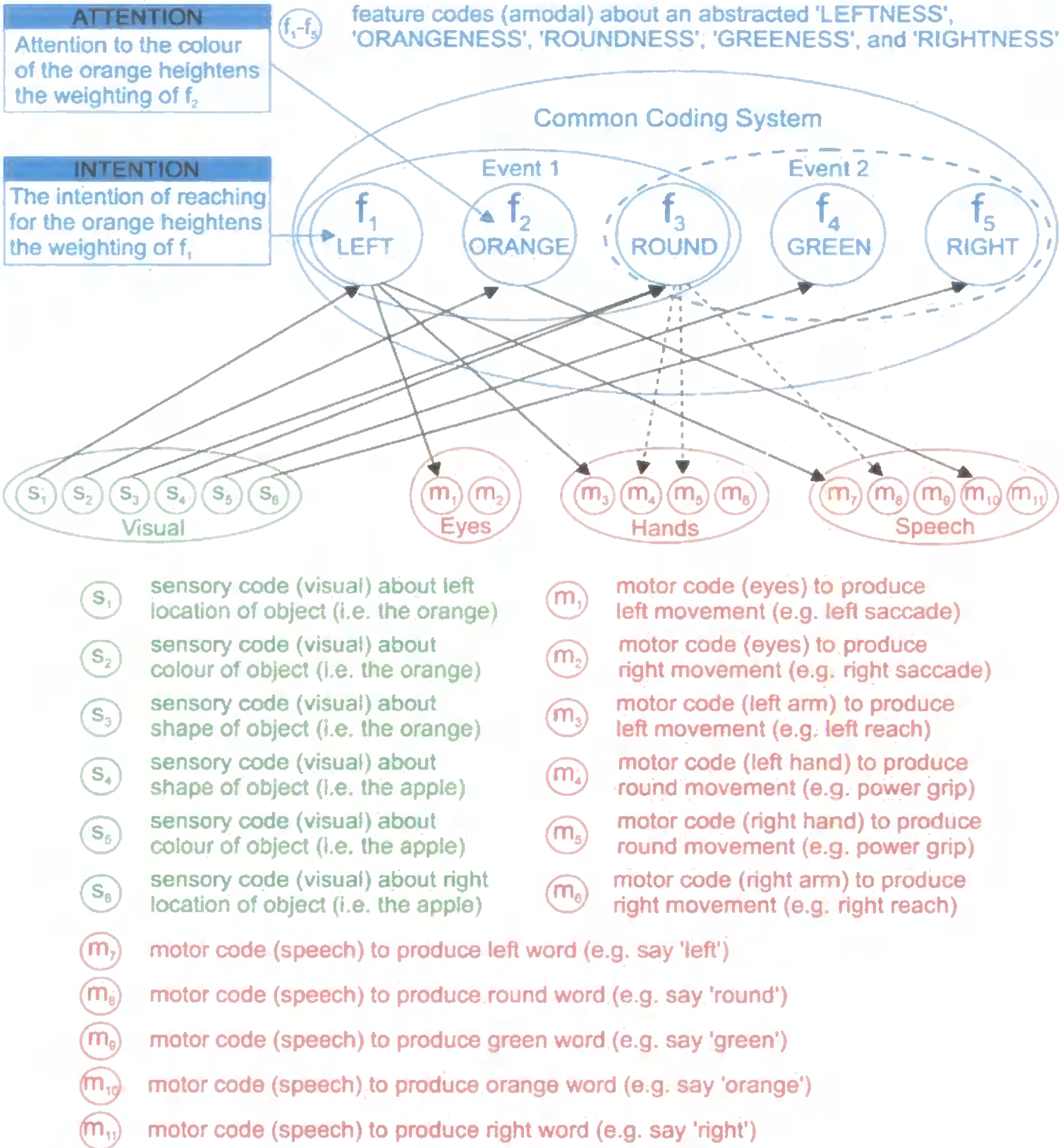


Figure 2.4 Adapted from Hommel et al (2001). Integration of feature codes into event representations. Feature codes that are activated by external stimulation or internal processes are bound into separate, coherent event structures. In the example, an apple and an orange are seen, but attention is directed towards the orange. Each of the two represented events includes two unique features (f_1, f_2 and f_4, f_5, respectively), but the two represented events overlap with respect to one feature (f_3). The solid-line ellipse indicates integrated features (continuing to solid-line efferent connections), and the dashed-line ellipse indicates partially suppressed features (continuing to efferent dashed-line connections). Activation is partiallly suppressed in efferent grey connections, and enhanced in efferent black connections.

TEC proposes that integration occurs via a binding mechanism, such as the temporal coupling or activation synchronisation of feature codes (e.g. Singer, 1994; Treisman, 1996) [23]. There are two distinct phases to event coding. Firstly, an event is perceived or planned by activating corresponding feature codes. The activation of another event may be facilitated if it shares overlapping features. Secondly however, as soon as the perceived or planned event becomes integrated, the activation of the other event(s) is suppressed or inhibited. Thus only one event representation can be simultaneously activated and integrated at any one time (as illustrated in Figure 2.4). As TEC does not develop the idea of binding in any detail, certain assumptions have been made. For example, it is assumed in Figure 2.4 that the suppressed activation of Event 2 spreads to its associated motor codes, thus inhibiting unwanted motor responses. In this way, there is selective control of actions through facilitation and inhibition.

TEC suggests that context, intention and attention all modulate the activation and integration of event codes (see Figure 2.4). Starting with the assumption that a particular feature is relevant for a current task, that feature's code will be weighted highly. The activation level of this feature code will be greater than that of a task-irrelevant (yet nevertheless associated, and hence partially activated) feature code. Furthermore, the higher the activation level of a particular feature code (e.g. a task relevant one), the more strongly and/or likely it will be integrated into a useable event code. Thus feature-weighting can influence both activation and integration. Features are weighted according to their task relevance, and TEC suggests that in terms of perception, feature weighting is an attentional process that selectively prepares the cognitive system for features that might be relevant (to-be-attended) or irrelevant (to-be-ignored); and in terms of action planning,

[23] This is known as the binding problem. However, O'Regan and Nöe (2001, p. 51) argue that the binding problem is a fallacy, in terms of both the temporal and conceptual unity of experience, "What explains the temporal unity of experience is the fact that experience is a thing we are doing, and we are doing it now…What explains the conceptual unity of experience is a thing we are doing, and we are doing it with respect to a conceptually unified external object". Nevertheless, if one holds a representational stance (as TEC does, but O'Regan and Nöe do not), the consensus is that binding is a genuine problem that needs addressing, and as the brain apparently solves the binding problem by synchronising the things we are doing with the fact that we are doing them now, O'Regan and Nöe's position is implicitly held anyway.

feature weighting is an intentional process that selects features that are relevant to an intended effect (i.e. a to-be-produced event)[24].

2.4.3 Distinguishing between sensation and perception

As mentioned earlier, TEC is not consistent about its assumption (Assumption 3) that feature codes are common to both proximal and distal effects. After pointing out the inconsistency (see Box 2.2 below), the following suggests that the confusion arises from a failure to adequately distinguish between sensation and perception.

Box 2.2 Selected quotations revealing TEC's inconsistency

Proposition A: Common codes are proximal and distal codes

"... the distinction between intrinsic, natural, body-related action effects on the one hand and extrinsic, artificial feedback on the other... TEC leads one to doubt that such distinctions make sense at all, because for a cognitive system any information is necessarily extrinsic and natural—the only thing that counts is the event the information refers to...the instruction had the expected effect in persuading the key group to code their actions in terms of proximal effects (keypressing or finger moving) and the light group in terms of more distal effects (light flashing)...coding actions in terms of artificial, "extrinsic" effects is no less easy and natural than referring to more "intrinsic" feedback sources". Hommel et al (2001, p.26)

"...the model does not distinguish between movement effects that differ in their degree of remoteness, such as proximal sensations (e.g., feeling the arm moving toward the light switch) and distal consequences (e.g., experiencing the light going on)...from the internal perspective that the cognitive system necessarily adopts, there is no qualitative difference between a body sensation and an external event." Elsner & Hommel (2001, p. 231)

Proposition B (contradiction): Common codes are exclusively distal codes

"...distal codes represent distal attributes of the perceived event...and /or produced event, but not proximal effects on the sensory surface or muscular innervation patterns... In fact, there is no way in which the sensory code representing a particular spatial distance would be similar to the muscular innervation pattern driving the hand over the same distance, suggesting that a match or mismatch between stimulus- and action-related codes can only be assumed on a more abstract distal-coding level, and it is this level our approach is referring to" Hommel et al (2001, p.14 - 15).

"...feature codes that represent a given perception or action effect do not refer to proximal, sensory or muscular regularities, but to distal attributes of the event, such as the perceived location of an external movement-contingent feedback light." Hommel et al (2001, p.32).

It is clear from Figures 2.3 and 2.4 (where there are sensory codes, motor codes and then common codes), that the distinction TEC *wants* to make is between sensation (i.e. proximal

[24] In Chapter 1 it was argued from an ecological perspective that action 'sets up' perception (Michaels and Stins, 1997). However, it was suggested that "sets up" was too vague, in a similar way to terms like 'resonating', or 'direct perception'. TEC's feature weighting offers a principled way by which action might 'set up' perception. Thus the weighting of features (which might simultaneously code for possible actions) can influence which properties of an event are perceived.

coding of sensory or muscular regularities) and perception (i.e. distal coding of percepts), but it is not sure how to do this. The inconsistency therefore arises because TEC has no principled way of distinguishing between sensation and perception.

Others have demonstrated a similar difficulty, which is again tied up in the (mis) use of the terms proximal and distal. Michaels and Stins (1997), for example, argued that distal stimuli are properties of objects and events themselves (e.g. affordances) and proximal stimuli are properties of structured arrays that are directly perceived (e.g. the information about affordances). This definition however, suffers from the issues related to the ecological notion of 'information' (as argued in Chapter 1), it bypasses sensation altogether through 'direct perception' (see Gibson, 1979, p.238), and furthermore, Michaels and Stins are not consistent or accurate in their usage of the terms (see Ehrenstein, 1997 for criticisms).

As we have seen in Box 2.2, TEC fails to provide a useful definition of proximal and distal stimuli. From reading between the lines however, a definition from TEC might read as follows: Distal stimuli are perceivable properties of our interaction with objects and events (that are coded as event codes, and might refer to action-contingent effects of varying remoteness) and proximal stimuli are the raw properties of patterns of stimulation available to our sensory systems (that are coded as sensory codes).

Sensation codes proximal effects and perception codes distal effects

One way of defining the terms 'proximal' and 'distal' is to adopt O'Regan & Nöe's (2001) two sets of laws of sensorimotor contingency, which make a broad yet principled distinction between sensation and perception:

1. *Sensation:* Proximal coding could be said to relate to the first set of laws that are specific to the sensory apparatus. In vision for example, eye movements distort and shift retinal stimulation. These shifts and distortions of retinal stimulation tell us about how the eyes work and not how the environment should appear. These sensations (that are defined by the sensory-apparatus and are independent of any categorisation or interpretation of events) might be said to code proximal information. O'Regan & Nöe (2001) argue that this first set of laws might underlie sensation.

2. *Perception:* Distal coding could be said to relate to the second set of laws that are specific to the sensory mode that reveals sensory *attributes* of objects and events. In vision for example, the visual attributes of an object are revealed by a retinal image that only provides a view in front of an object, whereas moving around an object makes part of it appear and disappear. These visual attributes (or sensory attributes revealed by other modalities) might be said to code distal information. O'Regan & Nöe (2001) argue that this second set of laws might underlie perception. It is important to note that perception is, of course, based on sensations derived from the sensory apparatus- just as TEC's event codes are based on sensory codes.

This distinction makes some sense of TEC's distal-level coding, which can now be meaningfully described as *perceptual* codes that are abstracted from *sensory* codes. A further point that adds to the utility of this explanation comes from O'Regan and Nöe's (2001) claim that the structure of the laws abstracted from the sensorimotor contingencies underlying perception (e.g. visuomotor contingencies associated with flat, concave, and convex surfaces, corners etc.) are *neural code independent* (return to footnote 9, p. 62 for an example). This fits well with TEC's common codes. They are not specific to a particular sensory modality, but instead integrate and abstract information from different modalities, such that common codes are also neural-code independent (e.g. "...distance, size, and location of stimulus and response only match with regard to a distal description of the environmental layout, but not in terms of the particular neural codes or activation patterns by which it is represented", Hommel et al, 2001, p.15).

A similar distinction between sensation and perception comes from Grush (2002), who argues that perceptual processes are amodal (i.e. neural code independent), accommodating all the different sensory modalities, imagery and motor imagery. Sensation however, is modal (i.e. neural code dependent). Grush (2002) argues that less sophisticated systems are engaged with their sensors, whereas more sophisticated systems set their goals in terms of objects and locations in the environment, and thus obtain information according to these terms.

The above discussion of sensation and perception will prove useful in the next chapter, where it is argued that the APH and TEC are closely related endeavours precisely because they both occupy the perceptual rather than sensory domain of coding.

2.4.4 An ecological criticism of TEC

In criticising TEC from an ecological perspective, Richardson and Michaels (2001) argue that TEC's event codes are arbitrary and ungrounded. They argue that event coding is an entirely mental process that is grounded neither in reality nor in information. This is a standard ecological argument. It assumes that the burden of information processing (e.g. forming event codes) is exclusively a mental one, and it wants instead to place this burden solely on the environment (i.e. on the 'information' in the ambient array).

However, it is argued below (see section 2.5), that the 'middle way' of the unitary theories discussed (including TEC) allow this burden of 'information' to be *shared* by environment and organism. This is most conspicuous in the Enactive approach, but is nevertheless evident in TEC. The environment is not pregiven- *it does not specify* what a feature code will be. A feature code is not pregiven- *it does not specify* how an environmental feature is coded. Thus TEC's feature codes evolve and change through experience, intention and context; and are *not* a pregiven, arbitrary or fixed set, but are based on a history of interactions in the world. For example, a colour (or more accurately, perturbations of light) *does not specify* that feature codes will always code RED. Rather, a single feature code (RED) can through experience and context become differentiated into a larger number of codes (CRIMSON, ORANGE etc.), and one can learn to distinguish between these codes.

The same can occur for action feature codes, such that LEFT may differentiate to LEFTWARD or LEFT-OF-BODY etc.

One suspects that Richardson and Michaels (2001) criticism is in part directed towards TEC's language of features or elements (such as green, red, big, left, right). However TEC is *not* proposing that there are arbitrary GREEN symbols floating around the brain; it is purely a language of convenience. Nevertheless, where Richardson and Michaels' (2001) criticisms do ring true is in their dissatisfaction with TEC's explanation of a distal level of coding. Richardson and Michaels (2001) are concerned that perception-action interdependence only occurs in the sphere that TEC refers to as "late perception" and "early action", and accuse TEC of dualism. However, as has been argued previously (section 2.4.3 above), TEC's distal-level coding is confusing because it does not adequately distinguish between sensation and perception. According to the arguments developed in section 2.4.3, so-called 'late perception' is actually perception (of which there are surely many levels), as opposed to sensation (which TEC might well take to be 'early perception'). So-called 'early action' is self-evident, it is action planning (plans that may prime actions, but need not demand that they are in fact executed). Richardson and Michaels (2001) are bound not to appreciate this distinction (even though TEC did not make it particularly clear), because they believe that firstly, information is specified in the world, and secondly, that this information is directly perceived. This is the specification principle of 'information':

> "...potential sensory stimulation is sufficient for accurate perception because the animal-environment interaction is *specified* in the spatiotemporal structure of ambient arrays. Specification refers to a lawful, 1:1 relation between patterns in ambient arrays and the aspects of the animal environment interaction that give rise to them"[25] Stoffregen and Bardy (2001, p.195).

2.4.5 Evidence for common coding

Having clarified TEC' s distal-level coding in terms of perception rather than sensation, the following briefly examines some evidence for common codes.

[25] As was noted in section 2.1, rather than the conventional ecological idea of various arrays (e.g. the optic array), Stoffregen and Bardy (2001) argue for a global ambient array of energy.

Synchronisation studies A.

Prinz (1997) refers to synchronisation studies (e.g. Aschersleben & Prinz, 1995, 1997) in which participants are required to tap their index fingers on a silent electrical contact plate in synchrony with the onset of a sequence of auditory clicks. While participants confidently believe they are synchronising their tap onsets perfectly with the onset of clicks, actually there is a negative asynchrony, such that tap onsets occur 30-50 milliseconds before click onsets. Prinz (1997, p.136) suggests that "... it is the taps' sensory or perceptual effects that get synchronised with the sensory or perceptual effects arising from clicks". In other words, Prinz is suggesting that synchronisation does not occur between auditory input and motor output (as evidenced by a 50 millisecond asynchrony), but rather occurs between the sensed or perceived click and the sensed or perceived tap.

It is of interest to note that, in a similar manner to TEC, Prinz (1997) is not sure what kind of effects are involved, as he refers to 'sensory' *or* 'perceptual' effects. He does however, settle on sensation, arguing that; "...synchrony is established in a common-coding domain where clicks are represented by sensory codes and taps by sensory feedback or effect codes".

In applying O'Regan and Nöe's (2001) distinction between sensation and perception, we can see that if Prinz wants to claim common-coding (which he does) then he is wrong to speak of sensory codes and sensory feedback. Certainly, it appears that it is not the kinaesthetic proprioceptive feedback of the finger moving down towards the key that is synchronised with clicks (and this proprioception might accurately be described as proximal feedback). What *is* synchronised, is the distal effect of the click (that is, the *perceived auditory attributes* of the click), and the distal effect of the tap (that is, the *perceived tactile attributes* of the key).

In this sense, it can be assumed that the perceived attributes of tactile and auditory objects/events are amodal, and consequently can be synchronised in a common-coding domain through the temporal integration of feature-effect codes. If these objects/events were classed as sensory (as Prinz does), then a common-coding explanation would not be legitimate. As O'Regan and Nöe (2001) argue, what allows interactions between different modalities of sensorimotor contingencies is the fact that they are all referring to neural-code independent attributes of objects and events, and not to raw modality specific sensations.

Hommel et al (2001) and Prinz (1997) review additional studies where taps produce artificial auditory effects. Introducing a delay between the (silent) finger tap and its artificial effect (a short tone), serves to increase the negative asynchrony between tap onset and click onset. This is taken as further evidence that the click is not synchronised with the motor code that produces the tapping movement, or with its kinaesthetic proprioceptive feedback. Indeed, the patterns of data are best explained in terms of a synchronisation between the click and a temporal average of the two perceivable effects associated with the tap (see Figure 2.5).

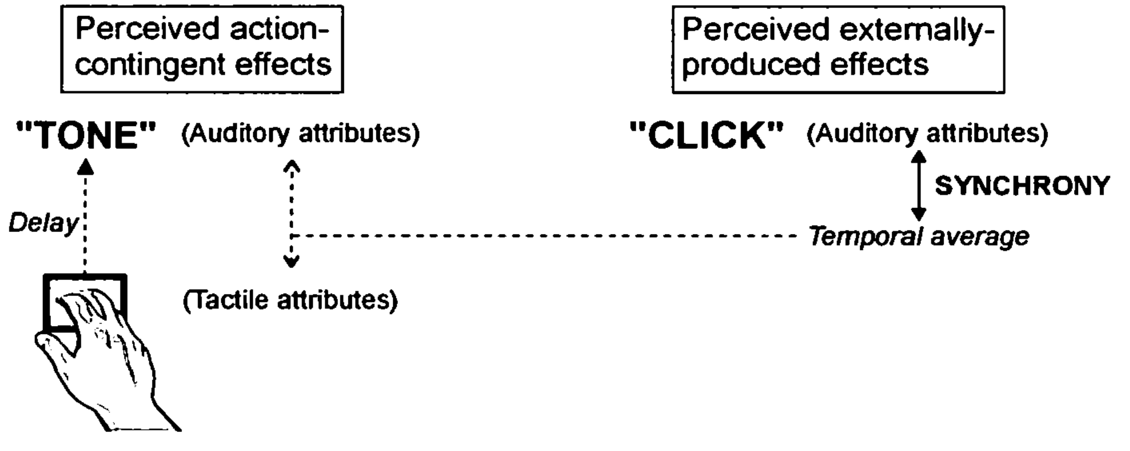


Figure 2.5 Schematic of increased negative asynchrony (or 'anticipatory error') between tap onset and click onset. The synchronisation actually occurs between a temporal average of the two perceived action effects (one natural and one artificial) and the perceived click.

Thus in terms of our previous understanding, the *perceived auditory attributes* of the click (distal) are synchronised with a temporal average of the *perceived tactile attributes* of the key (distal) and the *perceived auditory attributes* of the tap (distal). Once again, as all of these effects are perceptual they can all be represented in a common coding domain.

Synchronisation studies B.

If common-coding is to be demonstrated in a way that avoids any possible confusion between proximal sensation and distal perception, then a study is needed that pits a purely motor-based source of information (e.g. muscular innervation patterns that are easily categorised as proximal) against a purely perceptual source of information (such as a visually perceived event that is easily categorised as distal). Enter a recent study by Mechsner, Kerzel, Knoblich and Prinz (2001). It is a well-known phenomenon that people have a spontaneous tendency to produce bimanual movements that have mirror symmetry (for example, note the mirror symmetry that occurs when you make small circles simultaneously with your two index fingers). Even when initially asymmetrical movements are made, there is a tendency to slip into symmetry (but not vice versa). Traditional interpretations of this phenomenon have assumed a tendency to co-activate homologous muscles. Under this interpretation, the symmetry that occurs is due to proximal constraints (muscular and motor).

Mechsner et al (2001) however, have demonstrated that this phenomenon has a purely perceptual basis (i.e. symmetry arises at a distal-coding level). In their third experiment, Mechsner et al (2001) instructed participants to circle two flags inwards and maintain the visual circling pattern either in mirror symmetry (see Figure 2.6b) or in antiphase (see Figure 2.6c). As a clever design twist, the two hidden cranks that operated the flags produced different temporal effects on each flag. The left crank operated its flag directly, such that the left flag circled directly above the left crank and hand. The right crank however, was geared such that the right flag circled in a 4:3 frequency ratio to the right crank and hand. If we consider the two *hands* circling in temporal synchrony, then the right flag would circle more slowly than the left flag (i.e. the flags themselves would not circle in temporal synchrony).

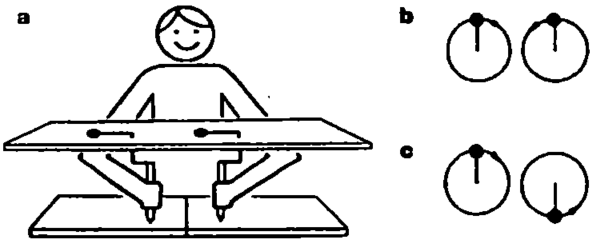


Figure 2.6 Apparatus used in Mechsner et al's (2001) Experiment 3, and instructed synchronous circling patterns of the flags. a. Apparatus. The participant circles two visible flags using his or her hidden hands. The left flag moves coincidentally with the left hand whereas the right flag moves according to a well defined angle and/or frequency transformation with regard to the right hand (see text). b. Symmetry, that is, 0° relative angle. c. Antiphase, that is, 180° relative angle. From Mechsner et al (2001).

When people circle their hands in a horizontal plane, the tendency towards symmetrical synchronisation means that it is almost impossible (unless trained) to produce circling patterns under non-harmonic frequency ratios of the hands, such as a 5:4 or 4:3 frequency ratio. Consequently, because bimanual circling in a 4:3 ratio is practically impossible for a naive participant, no body-oriented strategy could bring about iso-frequency, symmetry or anti-phase in the flags. Furthermore, owing to the frequency transformation in the right crank and flag system, symmetry or antiphase in the flags could not be predicted from the corresponding hand movement pattern (which is identical in both cases).

The results revealed that participants could circle flags in symmetry and speed up. They could also achieve antiphase (but this deteriorated at high speeds). Also, switches into symmetry occurred. Mechsner et al (2001) concluded that symmetry and antiphase in the flags were achieved in visual space despite the absence of a specific translation of characteristic body activity patterns into perceptual patterns. Furthermore, participants could easily perform otherwise 'impossible' body movements in order to achieve instructed flag movements. Mechsner et al (2001) further argued that the tendency towards flag circling symmetry (independent of what the hands were doing) supported the notion that the phenomenon of symmetry tendency in bimanual circling is purely perceptual.[26]

In terms of TEC, the perceptual basis of synchronisation-for-symmetry phenomena bears all the hallmarks of a common representational domain in which distal effects of a perceived event are coded. The proximal effects associated with the activity do not play a part in this common coding. As Mechsner et al (2001) concluded,

> "...not only spontaneous but also intentional symmetry and antiphase are clearly organized exclusively in the domain of perception and perceptual imagery...We speculate that voluntary movements are, in general, organised by way of a simple representation of the perceptual goals, whereas the corresponding motor activity of, sometimes extreme, formal complexity is spontaneously tuned in."

For 'spontaneously tuned in', read the automatic activation of associated motor patterns.

2.5 The middle way of unitary theories

The following attempts to tie together the core ideas expressed by the theories discussed in this chapter. It is argued that these unitary theories all complement what Varela et al. (1992) have called 'the middle way'. The Enactive Approach call their level of explanation 'the middle way'- an examination of the human experience that provides for both its reflective and its immediate lived aspects; where the distinction between the self and the world is acknowledged, yet so too is the continuity between them (Varela et al, 1992, p.3-4). For O'Regan and Nöe (2001), this middle way can be seen in the brain's adaptation to and abstraction of the second set of laws of sensorimotor contingency that are neural-code independent. For Edelman (1992), this middle way can be seen in the environmental selection of higher-order 'global mappings' that account for the present and the past of lived experiences. Edelman (1992) argues that reentry combined with memory (which itself is explained by the three tenets of the TNGS) provides the essential link between physiology and psychology. The distal-level coding of TEC appears to occupy this level of explanation. Thus for Hommel et al (2001), the middle way assumes that perception,

[26] Additional experiments revealed a similar perceptual basis for a symmetry tendency in the bimanual synchrony of left-right finger oscillation patterns, and for a symmetry tendency in bimanual finger tapping.

attention, intention and action all operate on a common representational domain in which common codes do not distinguish between previous, current or future perceptions and actions.

The behavioural activity

Central to this middle way is the emphasis on the behavioural *activity* rather than a fixed, specified or 'pregiven' behavioural functionality. The importance of the behavioural activity has already been mentioned in Chapter 1 and in section 2.3.1 (see also Box 2.3 below). This sentiment of activity-based coding is broadly comparable to the behavioural layers of Brooks' Genghis (which can be decomposed by activity but not by function); the 'viability' function of the Enactive Approach (where interactions are not fixed or prescribed, but simply viable within the context of a current activity); O'Regan & Nöe's (2001) laws of sensorimotor contingency, the mastery of which must be exercised in a current activity (again, these laws are not fixed, but are based on a history of sensorimotor contingencies); and the 'degenerative' rather than fixed neuronal groups of Edelman (1988), that are constrained (and not specified) by value. This activity-based coding shapes the function of representations (as illustrated by Condition 3 of the definition of representations offered in Chapter 1).

A number of developmental and adaptation studies have similarly revealed the importance of the behavioural context of an activity. Clark (1997) for example, reviewed a study by Thelen and Smith (1994) where two different age groups of infants (the youngest were crawlers, and the oldest were walkers) were placed at the top of slopes of varying steepness. Crawlers dauntlessly tackled slopes of 20° and greater (usually falling). Walkers were wary of the same slopes and sometimes slid down them or refused to descend. As crawlers increased in experience they learned to avoid steep slopes. Remarkably however, when the crawlers first began to walk, they tackled steep slopes with the same reckless abandon as they had when first crawling. They had only learnt about steep slopes within the behavioural context of crawling, and could not apply this practical knowledge to the new experience of walking.

A similar phenomenon arises in perceptual adaptation studies where adults wear image-shifting glasses. Thus Clark (1997) reviewed a study by Thach, Goodkin and Keating (1992) where adults gradually adapted to glasses that shifted the image sideways, while performing the task of throwing darts overhand. After a time wearers adapted to the glasses, and dart throwing became as accurate as it had been before wearing the glasses. Still wearing the glasses, when asked to throw the darts underhand, or with their non-dominant hand, performance showed no comparable improvement. They had only adapted to the glasses within the behavioural context of dominant overhand throwing, and could not carry it over to other behavioural contexts (even in the same task domain).

Box 2.3 The middle way of TEC

As well as 'sensory codes', 'perceptual codes', 'action codes', 'feature codes', 'effect codes' and 'event codes', TEC frequently refers to its 'common codes' as 'cognitive codes' (see previous section for the inherent confusability of these codes). Indeed, here are some of the various classes of codes that Hommel and his colleagues have referred to:

1. 'abstract codes', 2. 'action codes', 3. 'action concepts', 4. 'action-feature codes', 5. 'action files', 6. 'cognitive codes', 7. 'common codes', 8. 'distal codes', 9. 'effect codes', 10. 'event codes', 11. 'feature codes', 12. 'motor codes', 13. 'object files', 14. 'perceptual codes', 15. 'proximal codes', 16. 'response codes', 17. 'sensory codes', 18. 'stimulus codes'...

Interestingly, the culmination of years of research from Hommel and colleagues has resulted in the more-or-less definitive 'event code'. It is notable that for TEC, the most productive way of understanding a wide variety of mental capabilities comes from a coding perspective that incorporates the entire behavioural event (or as others prefer, the behavioural *activity*). This necessarily takes into consideration the ongoing interactions between the brain, the body and the environment.

This holistic solution underlies an important point; attempts to isolate distinct structures or processes in perception, action or cognition- or even in the environment (e.g. Gibsonian 'information')- may be misleading. Instead, one can consider the *activity* (or the *event*) that characterises the dynamics of coding. As has been argued earlier, the various 'middle ways' of the unitary theories discussed, consider 'cognition' as a dynamic activity. This is couched in terms of higher-order global mappings (Edelman), modes of sensorimotor exploration (O'Regan and Nöe), activity producing behavioural layers (Brooks), second-order structural couplings (Varela et al), or event codes (Hommel et al).

While the theories discussed are all relatively recent, these ideas are not new. One of the earlier proponents of 'action-oriented perception' that stresses the importance of the whole ongoing behavioural activity (including affordances, current goals, tasks and internal states for determining what is perceived) was Arbib (1972).

Furthermore, various perception-action compatibility studies have demonstrated that within an experiment, compatibility effects can be found for different aspects of the task (such as location-action effects for a key press, or for the light bulb itself), depending on how the participants strategically interpret (either implicitly or through instruction) the activity they are engaged in (e.g. Guiard, 1983; Michaels & Stins, 1997; Stins and Michaels, 1997; Stins and Michaels, 1999; Hommel, 1993).

2.5.1 Summary of Chapters 1 and 2

Chapters 1 and 2 have attempted to recommend the utility of adopting increasingly popular 'embodied' approaches to cognition. This has taken the form of an initially broad introduction (Chapter 1) followed by an increasingly theory-specific coverage (Chapter 2). In adopting an embodied perspective, it has been argued that there has been a move away from strict linear-stage information processing accounts that see perception and action as two separate and incommensurate endeavours that need to be bridged by computational translation. Instead, perception and action are seen as closely related (if not indistinguishable) endeavours that naturally interact by means of highly parallel, distributed and dynamic processes. In terms of S-R-C phenomena, this change of perspective has made linear-stage coding accounts (that are founded on arbitrariness) seem somewhat inappropriate and dated. Nevertheless, purely ecological accounts have failed in some respects as a convincing alternative owing to their scientific unaccountability (through terms such as 'information in the optic array', 'direct perception', 'resonance' and 'attunement').

This change of emphasis has had serious implications for representationalism. Consequently, there has been a need to consider more carefully just what a representation might be. In doing this, there has been a move away from highly specified, detailed internal representations towards less specified, less detailed action-oriented or personalised kinds of representation (think André rather than Michelangelo). The functions of these representations are flexible enough to adapt to the changing context of a behavioural activity (just as André's sculpture can be seen as a pile of bricks or an insouciant masterpiece).

Discussion of a variety of separable-but-linked and unitary approaches has culminated in an understanding that perception and action are best characterised as amodal or neural code independent processes, such that complex interactions are possible between attention, intentions, goals, different modalities, perception and action planning, perception and imagery, pseudo-independent visual systems and so on. In this way it makes sense to characterise perception and action in terms of a 'middle way' - a process-driven dynamic loop that can be interpreted within the context of a history of sensorimotor interactions and a current behavioural activity. This view is supported by insights from behaviour-based robotics, neurophysiological, behavioural, adaptation and developmental studies.

The remaining chapters apply the ideas discussed above to the interpretation, development and objective testing of the APH.

3. The Action Potentiation Hypothesis (APH)

Contents

3.1 Interpreting the APH from an embodied perspective

This Chapter attempts to assimilate the insights from embodied cognition with the APH; a hypothesis that proposes the automatic potentiation of motor activity afforded by certain features of a visual object (see Chapter 1). It is argued that such a basic proposal is fully compatible with an embodied approach to cognition. There are however, questions that remain concerning the specificity of these so-called 'micro-affordances'. After examining some sources of evidence that might support the APH, the experimental work that follows in this and later chapters addresses the specificity of micro-affordances, both in terms of the actions that are afforded and the visual attributes that might be evoke such affordances.

Tucker and Ellis (e.g. Tucker & Ellis, 1998, 2001; Ellis and Tucker, 2000) draw on a range of sources to support their developing APH. The essence of their argument is this- there is a growing body of evidence (neuropsychological, neurophysiological and behavioural) that suggests perception and action are intimately linked. The cumulative impact of this kind of evidence recommends the plausibility of the APH (see Tucker, 1997 for a selective review). The following subsections take a critical look at some of these sources of evidence.

3.1.1 Neurophysiological sources of evidence

In the quest for the neural correlate for consciousness, representations or some mental faculty or other, neurophysiological data is often assumed to be the most direct source of evidence for theories of mind. Thus when single cell recordings reveal cells in the parietal cortex that are sensitive to both visuospatial stimulus properties and the type of grip required to interact with them (e.g. Sakata, Taira, Murata and Mine, 1995; Taira, Mine, Georgopoulos, Murata & Sukata, 1990; Sakata, Taira, Mine & Murata, 1990; Stein, 1992), there is a temptation to give them a representational interpretation. Thus for Tucker and Ellis (2001, p.770), this kind of sensorimotor integration might be an "ideal candidate for representing affordances", whereas for Hommel et al. (2001, p.20) these same populations of neurons are "the neuroanatomical substrate of the common codes". That TEC's common codes and micro-affordances both draw on the very same source for supporting evidence suggests the similarity of their ideas.

However, understanding the response properties of individual cells is not the same as understanding a pattern of activity over space and time that itself arises through the *connectivity* of these cells. Tucker and Ellis (1998) recognised this problem, arguing that there is no reason why response properties of cells should equate with their representational role in as complex a network as the brain.

Furthermore, according to the Enactive approach, there is no reason why we should expect a passive mapping of environmental features at all (as demonstrated in work on colour perception). Thus finding a group of cells that behave a certain way to a certain stimulus does not necessarily mean that this is their sole function (e.g. Lehky and Sejnowski, 1988), or that under different conditions they might not produce a different pattern of activity to the same environmental stimulus. For example, Freeman and Skarda (1985)[27] demonstrated that there is no one to one mapping of a specific odour to a global pattern of activity in a rabbit's olfactory bulb. Firstly, an odour specific pattern will not emerge from a globally chaotic state at all unless the rabbit has some motivation (e.g. intention, attention or expectation). What is more, a specific odour produces a stereotypical pattern of activity that is soon changed under any number of conditions (e.g. learning a new odour changes the patterns of *all* previously learnt odours, and associating an odour with a different behavioural response changes that odour's stereotypical pattern). In short the same environmental stimulus can produce different neural states depending on the *behavioural activity* that an organism is engaged with.

From the opposite perspective, O'Regan and Nöe (2001) convincingly argue to similar ends that exactly the same neural state can underlie different experiences. Thus when PET scans (e.g. Grezes and Decety, 2002) or fMRI scans (e.g. Grezes, Tucker, Armony, Ellis, & Passingham, in submission) reveal certain patterns of activity in appropriately visuomotor

[27] As reviewed by Varela et al. (1991); and Franklin (1995).

areas that apparently support the APH, it should not be taken for granted that a snapshot of '*the*' object representation has been 'lit up' for all to see.

If a representational gloss is to be credible representations must be conceived of as dynamic. As was argued in Chapter 1, one way of doing this is to allow their functions to simply be viable (i.e. loosely constrained) rather than specific, fixed and prescribed. As a case in point, consider TEC's evolving feature codes that are abstract enough to influence a wide range of actions, and that do not represent a direct mapping of environmental features thanks to their susceptability to the context of an event with regard to an agent's situational context, intentions, goals and attention. It is argued later that the APH also allows this flexability by arguing that micro-affordances can be modulated and elaborated through semantic knowledge, context and intention.

This is an important point, for as mentioned before, Brooks' (2002) rejection of a traditional representational account for his robots was based on the fact that their high-level behaviours were not reflected directly in any of their simple computations. According to a 'viability function' view of representations however, this lack of transparency is exactly what would be expected (one could not, for example, pin down *exactly* what an abstract LEFT feature code represents). Indeed, reviews of motor representations (particularly those involving population coding for the direction of forthcoming movement) by Georgopoulos (1986, 1991, 1992) reveal what a spatial code might look like, and its functionality is by no means specific (it does not for example control a specific muscle contraction, but is instead rather abstract).

For example, Alexander and Crutcher (1990)[28] trained monkeys to guide a cursor towards a moving visual target using their forearm. In the standard task, the target and cursor moved in the same direction as the forearm. In the dissociation task, the target and cursor moved in the opposite direction to the forearm. The activity of 40 % of the cells in the motor cortex, 36 % in the supplementary motor area, and 38 % in the putamen showed

[28] As reviewed by Geourgopoulos (1991).

selective discharge prior to all 'pre-planned' (anticipated) movements of the cursor (left or right), *irrespective of the direction of the limb movement* (elbow extension or flexion). Geourgopoulos (1991) argued that changes of activity in the central motor structures in tasks involving visually guided movements reflect higher order processing of visuomotor information (rather than exclusivity to upcoming muscle contractions)[29]. These results might even be interpreted as reflecting the motor activation associated with TEC's anticipatory feature-effect codes, which code distal effects (e.g. the anticipated direction of the cursor movement), but not proximal effects (e.g. muscular contractions).

It is only when a representation leans towards a 'prescribed' symbolic level, that one might realistically expect to pinpoint some interpretable causal element (such as a so-called 'grandmother cell'). What is more, as has already been argued with reference to Dennett's (1995) giraffes and Brooks' (1991) Genghis (see Chapter 1), examining in micro-detail the causal facts of any number of tiny interactions would not tell us much about the kind of questions we are interested in anyway. This same insight should be applied when attempting a representational interpretation of a range of neurophysiological data.

3.1.2 Behavioural sources of evidence

Given the above notes of caution, behavioural data is therefore crucial to our understanding of representations, although this does not come without its own set of interpretative pitfalls. With a view to testing the APH, Ellis, Tucker and colleagues have performed a series of choice reaction-time experiments that adopt the S-R-C paradigm.

The basic claim is that that a seen or currently represented object activates elements of an associated action (a micro-affordance) for at least three elements of a reach-to-grasp action; namely hand of response, wrist rotation and grip type. In a series of experiments, participants were shown either real everyday objects, or photographs of them on a monitor. While viewing the object (or recalling an object), participants made some response (that

[29] Interestingly, Geourgopoulos (1991) reports evidence that only a fraction of motor cortical cells actually relate to muscular activity. Ironically, despite being visuomotor representations, the nature of this kind of higher-order processing reminds one of representations that are 'general-purpose descriptions' in a Marrian sense.

mimicked a likely object-related action) according to some otherwise arbitrary object category (such as whether it was manmade or natural). The general finding from these experiments revealed that despite an action-irrelevant response assignment, responses were faster and more accurate when a property of the seen or recalled object (e.g. its size or orientation) coincided with a response that mimicked the kind of action that would be most appropriate for interacting with that object property.

For example, when objects such as jugs and saucepans were oriented such that a handle pointed into the left or right visual field, key presses were faster and more accurate for the hand of response that was the same side as the object's handle (see Figure 3.1 part A). This was the case even though responses classified whether the object was upright or inverted. In other words, the object's horizontal orientation was task irrelevant.

When vertically or horizontally oriented objects such as bottles were responded to with clockwise or anticlockwise wrist rotations (always from a starting position of 11:00), then responses were faster and more accurate when the wrist rotation was appropriate for the object's orientation (see Figure 3.1 part B). For example, clockwise rotations were most compatible with vertically oriented objects. This was the case even though responses were signalled by an arbitrary high or low pitched auditory tone. In other words, the object's horizontal or vertical orientation was task irrelevant.

Similarly, when a series of objects that were large or small in size were responded to with responses that mimicked the kind of grip one might use (e.g. a precision grip that one might use to pick up a grape, and a power grip that one might use to wield a hammer), these responses were faster and more accurate when they were object-size compatible (see Figure 3.1 part C). This was the case even though responses classified whether the object category was manmade or natural. In other words, the object's size was task irrelevant.

When the task demanded that objects were recalled, a similar pattern of results was obtained. Thus recalling from a display of four objects the one object that was small evoked faster and more accurate precision grip responses, whereas recalling the one object that was large evoked faster and more accurate power grip responses (see Figure 3.1 part D). This was the case even though responses classified whether the object category was manmade or natural (an arrow pointed to the screen location of the now-absent object that was to be recalled). In other words, the object's size was task irrelevant.

Similarly, when an object had to be recalled from a sequence of objects, when this object was oriented, key presses were faster and more accurate for the hand of response that was the same side as the object's handle, regardless of the recalled object's position in the sequence (see Figure 3.1 part E). This was the case even though responses classified whether the object that was visually named after the sequence had stopped (e.g. 'JUG') had been present or not in the sequence (e.g. left response for present, right response for not present). In other words, the object's orientation was task irrelevant.

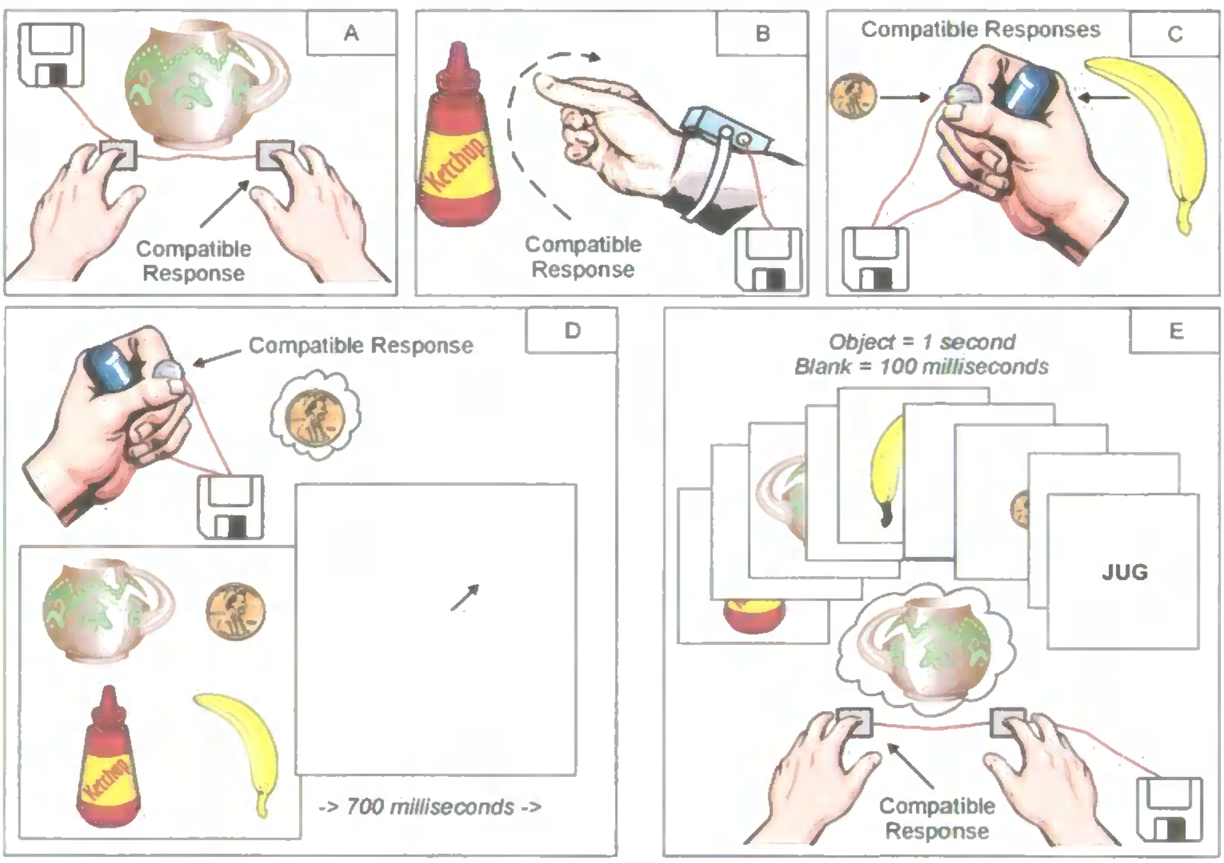


Figure 3.1 Behavioural evidence for the APH: A) Object-hand compatibility effects (Tucker and Ellis, 1998), B) Object-wrist compatibility effects (Ellis and Tucker, 2000), C) Object-grip compatibility effects (Tucker and Ellis, 2001), D) & E) Object-grip and object-hand compatibility effects for recalled objects (Derbyshire, Ellis and Tucker, in submission) 🖫 symbolises data sent to disc.

Thus in a similar manner to the Simon Effect described in Chapter 1, performance was facilitated (faster average reaction times and fewer average mistakes) when a task-irrelevant object property (such as orientation or size) coincided with an action-compatible response, despite responses being assigned according to some apparently arbitrary imperative stimulus (e.g. an object category, the pitch of a tone). In the experiments reported above, it is of particular importance to note that the task-irrelevant object property was relevant to an object-related action (such as a component of a reach-to-grasp movement).

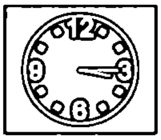
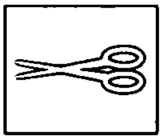
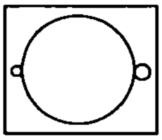
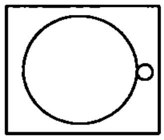
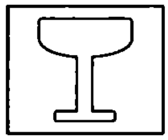
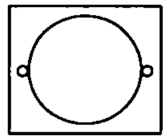
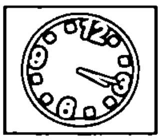
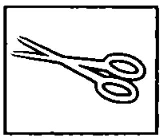
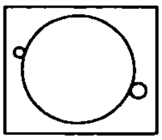
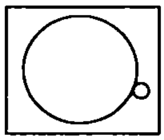
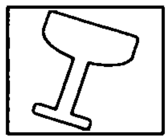
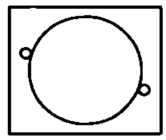
That similar results were obtained using visual imagery (Derbyshire, Ellis and Tucker, in submission) supports the views expressed in Chapter 1 (e.g. Kosslyn and colleagues; Grush, 2002) that perception and imagery are intimately related. It further supports the idea that a visual object representation (whether imagined or real) that implicates actions (whether imagined or real) involves the coactivity of the two visual systems. This is especially so because the dorsal system is often characterised as being a strictly on-line controller of actions (e.g. Goodale and Milner, 1992), and visual imagery is an off-line endeavour.

As might be expected from the discussion of S-R-C effects in Chapter 1, the findings reported above could be given an alternative arbitrary abstract coding explanation. From a DO perspective for example, object orientation could be coded along a 'left-right' dimension, thus overlapping with the 'left-right' response dimension (although Tucker and Ellis, 1998, suggested that the complex nature of the real objects presented may not have been codeable in simple binary terms). While an arbitrary abstract coding account of the object-wrist compatibility effects is less obvious, object size could be coded along a 'small-large' dimension, thus overlapping with a 'small-large' grip-type dimension.

Furthermore, a purely attention-based argument[30] for these kinds of compatibility effects has recently been offered as an alternative explanation of Tucker and Ellis' (1998) effects (see Box 3.1 for a synopsis of this argument).

Box 3.1 An attentional view of perception-action links

Anderson, Yamagishi and Karavia (2002) ran a small series of experiments using stimuli similar to those presented in the Table below (two-dimensional depictions of real or non-objects).

	Asymmetrical stimuli				Symmetrical stimuli	
	Object		Non-object		Object	Non-object
	a)	b)	c)	d)	e)	f)
Normal						
Clockwise-oriented						

The examples above show only clockwise orientations. The stimuli also included anti-clockwise orientations, and there were also opposite images of all stimuli (e.g. there was a clock face depicting 8:45). Separate experiments were run for objects and non-objects, and these included symmetrical and asymmetrical patterns. Participants were introduced to 'normal' oriented stimuli, and on experimental trials were presented with the oriented stimuli. Key press responses were made according to the stimulus orientation (e.g. left for anticlockwise and right for clockwise).

The general results revealed compatibility effects that reflected where attention was directed. Responses were facilitated when the hand of response was the same side as: the clock hands (a); the salient end of the scissors (for some it was the blades, for others, the handles) (b); the patch next to the central circle that was the largest (c); the patch next to the central circle (d); and the 'bowl' component of the wine glass (e). For f), there was no facilitation of responses as there was no salient feature to direct attention towards.

It was argued that all of the data could be accounted for simply by the directing of attention that formed the basis for motor signals automatically generated by the visual objects. The directing of attention was said to arise from an attentional bias that was induced by the visual asymmetry of the target objects. It was assumed that the non-objects and the clock-face in particular, did not afford any actions, yet they produced compatibility effects. Furthermore, in the case of scissors, because the compatibility effects varied (according to which end individuals deemed salient) it was argued that they could not have been based on behaviourally relevant actions afforded by the scissors. It was concluded that the 'affordance-hypothesis' (e.g. Tucker and Ellis, 1998) could not account for this data, and consequently the attention-based hypothesis was favoured.

[30] From this point on, this view will be referred to as the 'attention-directing hypothesis'

While Anderson, Yamagishi and Karavia's (2002) data does highlight the importance of attentional processes in perception-action compatibility effects; its dismissal of the 'affordance-hypothesis' may be unwarranted. Firstly, the potentially action-relevant property of the stimuli involved (an object's orientation) was the very property that participants were required to base their responses on. It is not surprising then that attention might be directed towards the areas of the object that best informed the viewer of its orientation. Secondly, and more importantly, while attention may play a significant role in some compatibility effects, it should not be seen as the only factor. Attention is just one link of many in a perception-action loop, and there is little point in asking the chicken-egg question of which came first, action or attention. Indeed, if pressed, it could be argued that the state of the action system (e.g. an action system that is partially prepared to make a left or right key press) 'sets up' or prepares perception such that attention is drawn to action-relevant properties of objects and events. This does not detract from Anderson et al's (2002) intuition that attention plays a substantial role in many compatibility effects- it does- but not in isolation of other links in the perception action loop (see for example, Tipper, Lortie and Baylis', 1992, 'action-centered attention').

Nevertheless, it is hoped that the material covered thus far has been sufficiently persuasive in recommending accounts of perception and action that do not stem from arbitrary sources of explanation (e.g. the DO model), or from isolated links in a perception-action loop (e.g. the attention-directing hypothesis), but rather from embodied and thus 'grounded' sources of explanation. Indeed, a number of findings in Chapter 6 support this argument.

3.1.3 The APH and the middle way

The following briefly argues that the APH would be at home in any and all of the separable-but-linked and unitary approaches described in Chapter 2 (i.e. 'the middle way'). Indeed, Ellis and Tucker (2000) aligned their hypothesis to Edelman's (1978, 1987, 1992) theory of brain development. Appealing to TNGS as a biological backdrop to micro-affordances, Ellis and Tucker (2000) suggested that the learning of coordinated actions such as reaching and grasping occurs through the gradual adaptation of neuronal groups. Those involved in a successful action (e.g. leading to contact with an object) become selected for that purpose. Once selected they can be said to represent possibilities for action, such that regardless of an intention to act, viewing an object automatically activates the motor codes needed to interact with that object in a certain way (e.g. a certain grip type). Thus Ellis and Tucker (2000) speculated that micro-affordances reflect the involvement of the motor components in global mappings.

The development of micro-affordances would be equally at home within the context of Elsner and Hommel's two-stage model, where associations between visual features and action features are acquired by chance, and then recruited for action control via anticipating action-contingent effects. Again, as with the APH, associated motor patterns are automatically activated regardless of an explicit intention to act (as assumed by the APH, the two-stage model and TEC, an explicit intention will increase the likelihood of executing the already activated movement codes).

Indeed, a micro-affordance could easily be described as an instance of a TEC feature code. For TEC, in perceiving a visual stimulus such as an apple, certain perceptual features are registered as abstract feature codes (e.g. LEFT, ROUND, GREEN etc). Some of these activated feature codes also serve as codes of action features (e.g. LEFT, ROUND), and activation automatically spreads (below threshold) to associated motor patterns (e.g. a left response, a power grip, a wide open mouth…). For the APH in perceiving a visual stimulus such as an apple, certain perceptual features (e.g. left location, round) are coded, and motor patterns for elements of an associated response are automatically activated below threshold (e.g. left response, power grip).

The only obvious difference between micro-affordances and feature codes might lie in the abstract nature of feature codes, which might appear to operate at a separate and higher level than those of micro-affordances. If this is a genuine difference, and micro-affordances are believed to occur through fundamentally direct links to action (i.e. they are not 'mediated' by amodal codes), then it must be assumed that they are sensation-action couplings of the most basic kind, rather than perception-action couplings. However, there are good reasons to believe this is not the case, and as the following argues, micro-affordances are almost certainly a perceptual phenomenon:

1) The APH concerns visual object representation (of which the micro-affordance part is said to contribute). As has been previously argued, when an object is seen, its visual *attributes* are revealed. The APH is concerned with how these visual attributes (size, shape, orientation, location etc.) automatically influence action. These visual attributes are necessarily the product of perception.

2) Various authors have recently argued that objects and events come into existence for an agent at a higher level than any direct one-to-one sensorimotor connections. This level deals with amodal or neural-code independent perception (e.g. O'Regan and Nöe, 2001; Hommel et al, 2001; Grush, 2002; Mechsner et al, 2001). Alternatively, for Edelman (1992), this level is achieved through reentrant signalling in and between higher-order global mappings. Whichever account is preferred, this level is a perceptual level.

3) Ellis and Tucker (2001) have emphasised that visual object representation comes about from the *conjoint activity* of the ventral and dorsal systems. This involves perceptual coding. Indeed Grush (2002) argues that the conjoint activity of the two visual systems amounts to amodal perception (which he characterises in terms of an amodal egocentric space/object emulator). Whatever interpretive slant is preferred, visual object representation is a perceptual feat, not a sensory one.

4) Derbyshire, Ellis and Tucker's (in submission) imagery experiments reported earlier add further support to the perceptual rather than sensory nature of micro-affordances. It is perhaps unlikely that a recalled image of an object would re-activate the precise patterns of sensory stimulation that would occur when seeing.

The APH and the behavioural activity

While the APH does not always appear to acknowledge the importance of a behavioural activity, it can easily be framed in these terms. While the overall impression of the APH may be one of reliable default visuomotor representations that occur simply through seeing an object (regardless of an intention to act); the APH does allow for the possibility of a subtler treatment. For example, Tucker and Ellis (1998, p.844) write,

> "According to this position, representing visual information involves representing information about possible actions and thereby potentiating them. One consequence of this is that intended actions are formed from, and informed by, already existing visuomotor representations. Actual actions are produced by the selection and elaboration of such representations".

This appears to say that micro-affordances reflect some kind of 'representational default setting' (although the APH itself does not make such a characterisation). A visuomotor representation exists (i.e. a default setting), and the intentions that come afterwards (e.g. I see an apple…I want to pick it up) are formed from and informed by this default setting (note that TEC is more liberal; intentions can also come first, directing the system both online and offline towards activating feature codes, and hence automatically potentiating motor patterns). Nevertheless, the APH proposes that these initially default representations can be elaborated, and intentions can modulate them. Crucially then the 'default setting' is neither fixed, nor prescriptive. It is this point above all others that allows us to see the APH as complementary to the middle way theories discussed.

To elaborate on this point, Tucker and Ellis (2001) acknowledge that semantic knowledge can influence the dorsal system, thus emphasising the conjoint activity of ventral and dorsal systems (e.g. Goodale and Humphrey, 1998) rather than an oversimplified functional dichotomy. Furthermore, they make a distinction between 'high-level affordances' (usually goal-directed) that arise from knowledge about an objects function, and 'low-level affordances' (micro-affordances) that arise from the purely physical characteristics of a visual object. In the absence of a current goal (or as the APH frequently says, 'regardless of any intention to act'), viewing an object triggers a default representational setting that is fairly primitive and quite general. When there is a current goal however, then selection, modualtion and elaboration of motor representations occurs. This is actually an attractive position to hold that is in keeping with many of the ideas discussed previously. The initially default representational setting is a perfect example of an action-oriented representation. To reiterate from Chapter 1, an action-oriented representation both describes a situation and suggests an appropriate reaction to it (Clark, 1997). Furthermore, an action-oriented representation is not dependent on separate representations of states of the world *or the cognitive systems goals for behaviour* (Chemero, 2000).

This initial goal independence also fits well with Brooks' (1991) subsumption architecture. Thus a low-level behavioural layer (that might connect perception to action in some way) goes about its business in a 'semantically blind way' (just as a micro-affordance might) until a higher-level behavioural layer modulates its activity through enhancement or suppression, in line with some more pressing behavioural goal. Thus while the APH has tended to focus on what it assumes to be the lowest level of affordance (micro-affordance), it is open to the possibility that within the context of a current behavioural activity, this affordance can be accepted, rejected or elaborated for real action generation.

These sentiments however, have not been tested formally by the APH, and indeed they have been confounded through its choice of stimuli. This is so for compatibility effects found when responding to small and large objects (e.g. a drawing pin or a hammer) with small and large grip types (e.g. a precision grip and a power grip); and for compatibility effects found when responding to oriented objects with a left and right hand responses. Owing to the design of these studies (where responses have always mimicked an appropriate action and the objects used have always had an everyday function), the following possibilities- *which are not necessarily mutually exclusive*- have not been addressed:

1. *The specificity of actions:* The action properties an object affords may be highly specified (in the sense of a detailed, fully specified motor program). As has been argued previously in Chapter 1, this kind of fully specified representation is not theoretically appealing. Nevertheless, such a case might be reflected behaviourally by the facilitation of only one specific action. Alternatively, the action properties that an object affords may be loosely constrained (i.e. general enough to be common to several actions, in the way that a common code might be). This might be reflected behaviourally by the facilitation of a range of actions. Also in keeping with this latter case, one might expect that actions can be 'set up' (i.e. *partially* programmed) by virtue of the physical context of a task. Here too, one might expect the facilitation of a range of actions, providing they have been 'set up' in the first place.

2. *The specificity of visual attributes:* It is possible that purely visual attributes (e.g. size, orientation, texture etc.) of an object reveal the physical possibilities for action, such that various properties of an action are automatically potentiated (through simply viewing the object regardless of any intention to act on it). This is the possibility that the APH emphasises. If this is the case, then just what are these visual attributes? For object orientation in particular, just what properties of an objects' orientation underlie an affordance for action? Perhaps it is crude visual cues such as spatially protruding features that afford action; or perhaps it is the angle of an objects' axis of elongation; or even the functional aspects of an object (such as an object's handle), whose significance for action may be learned through experience (see 3. below).

3. *The behavioural activity:* It is possible that perception-action compatibility effects are derived from a functional knowledge of what one does with an object (in a particular context), such as grasping the handle of a hammer or a saucepan (c.f. O'Regan and Nöe's, 2001, 'practical knowledge'). Tucker and Ellis (2001) attribute this functional knowledge to 'higher-level affordances', perhaps because it is thought to involve complex semantic processes. However, developmental literature strongly suggests that action is *initially* guided by just this kind of functional knowledge, which arises from trial and error rather than semantic insight (i.e. simply through doing; Maturana & Varela, 1987). It is only after considerable world experience that a more sophisticated awareness of the higher-level physical structure of objects and events emerges (e.g. Bremner, 2000; Lockman, 2000; Carey and Xu, 2001). For example, infants as old as 8 months fail to individuate

two objects that are in contact in the horizontal plane, treating them instead as if they were one object (Needham and Baillargeon, 1997).

Anecdotal observations support this insight. Thus when an infant tries to post shapes (stars, triangles, circles, squares) through a box with shape receptacles, the infant with a triangle will explore every possible shape receptacle. Perhaps the triangle is oriented incorrectly for its receptacle. The infant does not rotate it to fit, but instead tries each shape receptacle again. Once successful, it gradually becomes more and more likely that the triangle will be posted through the correct triangle receptacle. The infant does not yet have a sophisticated awareness of the higher-level physical structure of triangle shaped objects. Rather, functional knowledge of a specific triangle in the behavioural context of a specific game is being acquired.

Indeed, it makes sense to assume that early functional knowledge of this sort is the most basic source of affordance. Furthermore it is probably highly (or even totally) dependent on the *behavioural context of an activity* (in the sense of Thelen & Smith's, 1994 crawlers and walkers study). Developmentally later, insight and awareness of the higher-level physical structure of objects and events becomes increasingly sophisticated. This sophistication might enable a child to automatically *abstract* from and generalise to, those properties or dimensions of any number of new objects that are relevant for *goal-independent action* (i.e. physical-attribute based affordances such as micro-affordances). For TEC this abstraction might be abstract distal-level codes. For O'Regan and Nöe (2001) as we have seen, this means abstracting from an infinite set of possibilities a series of laws of sensorimotor contingency that codes various properties of objects (such as shape). Of course, as argued earlier, these initially 'default representational settings' (or abstracted series of laws) can be modulated by goals, intentions and so on.

3.2 Experimental Aims and Objectives

In investigating these different possibilities, the experimental chapters that follow used a S-R-C paradigm to explore the specificity of affordances related to an object's orientation; both with respect to the specificity of action properties afforded, and the specificity of visual attributes that evoke these affordances. The experimental work reported in this thesis therefore aimed to answer the following two questions:

1. "Do perception-action compatibility effects associated with an objects' orientation reflect a 'representational default setting' that is derived from a particular visual attribute (such as its axis of elongation within a particular dimension)."

2. "If so, does this 'default setting' reflect a fixed affordance for a specific property of an action; or a loosely constrained affordance that is abstract or primitive enough to influence components of a range of left-right actions. Furthermore, is this affordance modifiable with respect to the behavioural context of a currently exercised activity."

These questions are addressed by the following four objectives:

Objective 1: To replicate a study by Symes (1999) where object location and object orientation compatibility effects were obtained using left and right hand key-press responses to photographs of everyday objects. In this replication however, left and right responses are made with the feet, thus testing the hypothesis that a range of left-right actions can produce orientation-action compatibility effects (Experiment 3.1).

Objective 2: To test for orientation-action compatibility effects associated with diagonal two-dimensional lines, thus exploring the possibility that a specific visual attribute might afford left-right actions; namely the angle of an object's X-Y axis. Using these simple stimuli, different left-right response types are used in order to test whether any compatibility effects are specific to hands, or viable for a range of actions (Experiments 4.1 – 4.3).

Objective 3: To test for orientation-action compatibility effects associated with computer-generated three-dimensional cylinders that are oriented in three-dimensional space, thus exploring the possibility that a specific visual attribute (i.e. the angle of an object's primary axis within a particular three-dimensional plane) might afford left-right actions. Using these stimuli, different left-right response types are used in order to test whether any compatibility effects are specific to hands, or viable for a range of actions (Experiments 5.1 – 5.3).

Objective 4: To develop Objective 3 further by exploring how the orientation-action compatibility effects established in Chapter 5 might be modulated by various task manipulations that include stimulus onset asynchrony, apparent motion and participation in an ongoing dynamic activity (Experiments 6.1 – 6.3).

3.3 A brief justification of the reaction time experiment

The experimental work of this thesis involved a series of standard reaction-time experiments that adopted the S-R-C paradigm. The following briefly explains why such an approach is appropriate, despite popular criticisms that might suggest otherwise. As Hommel et al. (2001) noted in their response to the peer review for TEC; standard reaction-time experiments (such as those employed using an S-R-C paradigm) have received criticism and even ridicule for being both too simple (see 1. below) and too difficult (see 2. below). Following from this, there can be a tendency to promote dualism (by using tasks that are clearly delineated in terms of a stimulus and a response). This tendency was highlighted in Chapter 1, when reporting linear stage information processing accounts of S-R-C effects (e.g. Hasbroucq and Guiard, 1991; Kornblum et al., 1990). A major objection targets the highly artificial nature of the typical reaction-time experiment.

1. *Too simple:* On the one hand, the stimuli (e.g. arbitrary shapes, colours etc.), and the responses (e.g. key presses) *themselves*, are considered too simple. 'Real' visual stimuli involve complex scenes that are not static (e.g. look out of your window). 'Real' actions involve the unfolding and coordination of multiple components of action (e.g. throw your pen in the air and catch it).
2. *Too difficult:* On the other hand, the rule-imposed *relationship* between the stimuli (e.g. arbitrary shapes, colours etc.) and the responses (e.g. key presses) requires an often-arbitrary (hence difficult) coupling that is atypical to most everyday perception-action couplings.[31]

It is argued below that that these criticisms are not overly damaging, and can even be seen as a distinct advantage. Firstly however, the following suggests that an alternative approach of applying more ecologically meaningful experimentation, suffers from shortcomings that are the polar opposite of those presented above (these shortcomings are similar to those discussed in Chapter 1 with regard to the Ecological approach):

[31] However, as Hommel et al (2001) argued, many perception-action couplings do involve simple arbitrary responses to stimuli (e.g. keyboards, alarm clocks etc.), yet we are nevertheless proficient at using them. A pertinent example is games consoles, where a series of arbitrary symbols on a controller soon become tightly coupled to realistic action effects that are realised in increasingly complex and realistic virtual worlds.

1. *Too difficult:* On the one hand, the stimuli (e.g. real objects and scenes), and the responses (e.g. real sequences of actions) *themselves*, can be considered too difficult. In using complex visual scenes that are not static (i.e. real-world scenes) and complex coordinated actions (i.e. real-world actions), it is difficult to isolate the genuine influences of specific variables. In other words, in appealing to the real world, there is a danger of inscrutability owing to the vast number of interacting variables.

3. *Too simple:* On the other hand, within certain perception-action couplings the natural relationship between a stimulus (e.g. a punch bag) and a response (e.g. a punch) can be so simple as to be trivial (e.g. Adam et al's 1996 study discussed in Chapter 1).

Essentially the argument amounts to little more than a textbook debate on the pros and cons of various laboratory-based techniques versus more naturalistic techniques. It may be helpful to appeal to an analogy here. Consider the crash testing of automobiles. The reaction-time experiment's equivalent might be to test in a controlled environment the effects of various targeted impacts. For example a car might be stationary, and various impact devices target specific areas of the car at varying speeds and forces. Findings are extrapolated to the potential impacts of real-world car crashes, and research and design modifications are made accordingly. One is *not* obliged to develop theories of car design that are restricted to this unnatural crash-test setting (hence cars are designed to move and not to be stationary in a testing bay). Analogously, in terms of reaction-time experiments in perception-action research, one is *not* obliged to import dualism from method into theory[32]. The benefits of this highly controlled yet artificial approach include value and efficiency in terms of money and time, experimental control over specific variables, and repeatability. The drawbacks have been discussed above (it may be too simple and too difficult).

Alternatives might be to stage life-like car crashes involving two or more cars; piece together in a post hoc fashion the factors involved in real car crashes; or (ethics aside), to lie in wait of an accident near potential crash sites. This is analogous to the more naturalistic perception-action experimentation favoured by the Ecological tradition (e.g.

[32] Hommel et al (in press) make this same point in their defence. As a case in point, their theory explicitly attempts to avoid dualism. Thus TEC does not differentiate between a code for a percept and a code for an action. Similarly, the theoretical construct of an action-oriented representation avoids dualism by simultaneously describing a situation and suggesting an appropriate reaction to it.

analysing the whole event of hitting a baseball). The major benefit of this approach principally involves uncovering nuances that might only emerge through the complex dynamics involved in real-world perception-action couplings (or real-world car crashes). Drawbacks include those discussed above (it may be too difficult and too simple), and the numerous practical issues involved in carrying out and analysing such work.

Clearly both approaches have their advantages and disadvantages. Nevertheless, in asking the two major questions posed by this thesis (see section 3.2 above), the controlled reaction-time experiment is considered appropriate for the following reasons:

1. *Visual attribute specificity:* When 'ecological' stimuli have been used in reaction-time experiments; such as real-world objects or photographs of them (e.g. Tucker and Ellis, 1998); one is left with a lack of specificity that results from the relative inscrutability of these objects. Hence it is not clear from Tucker and Ellis' (1998) study what aspect or aspects of an object's orientation actually afforded left-right actions. The use of simple artificial stimuli that are carefully controlled along one or two dimensions allows for a finer-grained investigation (e.g. Chapters 4 and 5).
2. *Action specificity:* In using simple binary responses (e.g. hand key-presses) there is a danger of assuming that these responses are somehow privileged and exclusive (above and beyond the context of the experiment). Thus it has been assumed that facilitation for right hand key presses reflects an affordance for *specific* elements of a right-hand reach-to-grasp action (e.g. Tucker and Ellis, 1998). Nevertheless, this assumption can be challenged within the very same experimental framework, simply by comparing performance to other kinds of simplistic response, such as foot key-presses (e.g. Chapters 3-5).
3. *The behavioural activity:* While ecological-type experiments are ideally suited to engaging a participant in a meaningful behavioural activity (e.g. hitting a baseball), there is also plenty of scope within a reaction-time experiment to pursue this line of enquiry. By using artificial stimuli that can be passively manipulated (i.e. viewer-independent), or manipulated by action (i.e. viewer-dependent) within the context of a meaningful behavioural activity, there is an opportunity (which may not present itself in real world activities) to isolate and control specific aspects of this activity (e.g. Chapter 6).

3.4 Experiment 3.1

Objective 1: To replicate a study by Symes (1999) where object location and object orientation compatibility effects were obtained using left and right hand key-press responses to photographs of everyday objects. In this replication however, left and right responses are made with the feet, thus testing the hypothesis that a range of left-right actions can produce orientation-action compatibility effects.

In using feet as the response effector, this first experiment directly tested the possibility that perception-action compatibility effects associated with an oriented object are not exclusive to hands, but instead reflect an advantage for a range of left-right compatible actions. There are a number of hypotheses that can be generated in this light:

Action Specificity Hypothesis 1 (Exclusive): An object property (e.g. orientation) affords a left or right action property that is specific and exclusive to a particular action. Facilitation might occur for an interpretable affordance for left-right action (e.g. spatial hand key presses that are considered analogous to a reach towards an object), but *not* for other left-right actions (e.g. spatial foot key presses that are not obviously afforded).

This first hypothesis is close to the APH's early intuitions. Thus in interpreting their object orientation compatibility effects, Tucker and Ellis (1998, p.844) wrote,

> "Insofar as coding is involved, it arises from the potentiation of specific actions afforded by the object, in this case reaching by a particular hand, and consequently, the stimulus dimensions along which compatibility effects emerge are based on their relevance for controlling those actions."

Under this hypothesis, foot responses would presumably not be expected to reveal orientation-compatibility effects, as they are not the specific left-right actions (e.g. reaching with a particular hand) that are relevant to the object's orientation. Indeed, Tucker & Ellis (1998) reported some preliminary evidence suggesting that orientation-compatible effects were specific to a hand of response. In their Experiment 2, unimanual finger responses were made to oriented objects, and no significant interaction was found in mean RTs (although significance was obtained using median RTs). Nevertheless, the incorrect response data did appear to suggest an advantage for orientation compatible responses. Overall, Tucker & Ellis' (1998) Experiment 2 did not provide data convincing enough to draw strong conclusions regarding the specificity of left-right actions afforded by an object's orientation. Further doubts are raised concerning the affordance of a specific/ exclusive response, when a recent priming study by Phillips and Ward (2002) is considered. Here, S-R-C effects were produced that suggested an object's visual affordance evoked more *abstract* spatial response codes that potentiated, in a similar manner, a wide variety of lateralized responses corresponding to the visual affordance (e.g. crossed hands, uncrossed hands, *foot responses*).

Action Specificity Hypothesis 2 (Primitive): An object property (e.g. orientation) affords a primitive left-right action property that is a common component to many different actions. Facilitation might occur for a range of actions that share as a component a certain visuomotor primitive. The level of behavioural facilitation for this range of actions would be expected to be indistinguishable, since the basis for facilitation is exactly the same for all of them- namely a shared visuomotor primitive.

This second hypothesis is close to the APH's more recent intuitions. In explaining their position, Tucker and Ellis (2001, p.773) wrote,

> "… the kind of motor representations automatically generated by a visual object may be expected to remain fairly primitive, possibly restricted to visuomotor primitives that are common to many different actions. Visuomotor primitives of this sort correspond to what we have termed the micro-affordances of the object and would be more likely to be generated by a semantically blind system such as the parietal-motor systems".

The details of which component of an action a proposed visuomotor primitive might correspond to can only be speculated, but at a guess it might be expected that the initiation of certain left-right responses (e.g. spatial hand key presses, spatial foot key presses), might share the same spatial visuomotor primitive (or set of visuomotor primitives). Interestingly, this hypothesis does not necessarily suppose that whole classes of left-right actions are in some general sense afforded. Instead the APH's earlier assumption of specificity can be maintained (but this specificity cannot be treated as exclusivity). Thus it is possible that properties of a *specific* action are afforded by the orientation of a visual object (e.g. an oriented object might afford a specific component of a reach by a particular hand), *it just happens to be the case* that the visuomotor primitives involved in initiating this action are also common to other actions.

Action Specificity Hypothesis 3 (Weighted): An object property (e.g. object orientation) affords a specific left or right action property (that is weighted strongly), and the activation of this action property may spread by association to other action properties (whose weightings are weaker) within a distributed perception-action network. Facilitation might occur for an interpretable affordance for left-right action (e.g. a spatial key press that is considered analogous to a reach towards an object), and facilitation may also occur, but to a lesser extent, for other left-right actions (e.g. spatial foot responses that are not obviously afforded).

This third hypothesis resembles a standard associative account, where a specific (and perhaps exclusive) action property may be strongly activated on viewing an object. This action property is associated with other actions and hence activation spreads, but characteristic of distributed networks, weakens. Thus the primary motor recipient of a left-right affordance (e.g. a component of a reach with the left hand) will be strong, and its associated motor codes (e.g. for a left foot movement) will be activated to a lesser degree.

A slightly more sophisticated account that maintains the notion of shared visuomotor primitives is TEC's common coding approach. A given feature code (cf. visuomotor primitive) is common to many objects and actions, and thus a range of actions may be facilitated by a certain object property (as would also be expected under Action Specificity Hypothesis 2). However, according to the relevance for action in a given circumstance (that is modulated by intentions, attention and a history of interactions), TEC's 'feature weighting principle' (return to Figure 2.4) would predict that action properties that are *also* initially activated by viewing the object (such as a grasp for a left hand) will have the knock on effect of *increasing* the weighting of their associated codes. Thus those properties pertaining to the most relevant action (e.g. a common LEFT code, or a shared spatial visuomotor primitive) will be weighted more highly than those *very same properties* that might be activated by less relevant actions (e.g. a left foot response).

Action Specificity Hypothesis 4 (Set Up): An action that is 'set up' (i.e. partially programmed or soft-assembled) will heighten perceptual awareness (in terms of attention) to visual properties of the object that are relevant to that action. In turn that visual property will be more likely to afford the same properties of an action that have been 'set up'. Facilitation might occur for a range of actions that are compatible with an object property within the context of the physical parameters of the experiment.

This fourth hypothesis fits with the notion of a perception-action loop as discussed in Chapter 1 (where action influences perception and vice-versa). Accordingly, it would be expected that a physical and intentional preparedness to perform certain actions (e.g. left and right foot presses) should make these actions relevant to certain object properties (with which they might not normally share an obvious compatibility). *Unfortunately, the pattern of behavioural facilitation that might be expected under this hypothesis (e.g. the facilitation of both hand and foot key presses) does not necessarily distinguish between those expected under hypotheses 2 (similar facilitation) and 3 (differential facilitation).*

This 'setting up' of actions is complementary to TEC's common codes, which are indiscriminate in that they do not distinguish between a cause and an effect (or a stimulus and a response). This is so because a perceptual feature code (e.g. LEFT) and an action feature code (e.g. LEFT) are one and the same entity. Thus LEFT and RIGHT codes might be partially activated by a physical readiness to perform a spatial task, and perceptual features of an object that correspond to a 'leftness' or 'rightness' will already have been planned or anticipated (because they are represented by the same common codes), thus paving the way for a compatibility effect once the object is seen.

Overview

Experiment 3.1 reported below, replicated[33] Experiment 1 of Symes (1999). In the Symes (1999) study, photographs of a selection of horizontally oriented objects from the kitchen (e.g. saucepans, mugs, jugs etc.) and horizontally oriented objects from the garage (e.g. drills, hammers, screwdrivers etc.) were shown to participants. The objects were located

[33] This replication was identical to Symes (1999) with respect to the number of participants, the stimulus set and the procedure.

either on the left or the right of the screen (thus testing whether the relationship that spatial responses had with object location and object orientation were separate and distinct). As participants responded with a left or right hand key press to the object category (e.g. left response for kitchen, right response for garage), the location and orientation of the objects were task-irrelevant[34]. Compatibility effects associated with object location and object orientation were found to be distinguishable (and indeed, there were signs that they interacted with each other).

The Symes (1999) study revealed two findings associated with responses that are of particular relevance for this replication:

1. A statistically significant interaction between the object location (left or right) and the hand of response (left or right). Responses were faster and more accurate when they were compatible with the location of the object (e.g. a right response is compatible with a right object location). This result resembled a straightforward spatial S-R-C effect (i.e. a Simon-like effect).
2. A statistically significant interaction between the horizontal orientation of an object and the hand of response. Responses were faster and more accurate when they were compatible with the orientation of the object (e.g. a right response is compatible with an object oriented rightwards). This result resembled the orientation compatibility effect reported in Tucker and Ellis's (1998) study (return to Fig A. in Box 3.1).

In replicating the Symes (1999) study, Experiment 3.1 revealed similar results. For 1, the trend of the interaction was similar for response speeds and accuracy; while for 2, the trend of the interaction was similar for response speeds only. It is not surprising that foot responses produced a Simon-effect (location is an object property that has relevance for a vast range of actions), and the literature on the Simon Effect demonstrates its robustness across any number of response types that have a spatial dimension (see Chapter 1).

[34] Actually, it is over-simplistic to claim that object location was task-irrelevant, as clearly in order to categorise an object one must look at it (and therefore its location). Nevertheless, location was not the critical stimulus.

Of most theoretical interest was the observed interaction between the horizontal orientation of an object and the *foot* of response (where responses were faster when they were compatible with the orientation of the object). In this light, Action Specificity Hypothesis 1 (Exclusive) can be rejected. In comparing the data to the Symes (1999) study (which used hand responses), no statistically significant results were found between experiments. This finding does not support Action Specificity Hypothesis 3 (Weighted). However, the finding of an orientation-action compatibility effect using foot responses does supports the idea of an amodal action-oriented representation that operates at a common coding level (cf. visuomotor primitives common to many actions). This is in keeping with Action Specificity Hypothesis 2 (Primitive) and Action Specificity Hypothesis 4 ('Set up'). The motor component of this representation was presumably abstract or primitive enough to influence foot responses by virtue of either a) these responses sharing the same visuomotor codes as those of simple hand responses, and/or b) these responses having been 'set up' in the first place by the constraints of the experiment (even though foot responses have no obvious action-relevance to an object's horizontal orientation).

3.4.1 Method

Participants

Thirty undergraduate volunteers from the University of Plymouth were awarded either course credit or £2.50 for participating. They were all naïve as to the purpose of the experiment, had normal or corrected-to-normal vision, normal colour vision and normal motor control of the hands and feet. Age, gender and handedness were not controlled for, although the vast majority of participants were female, right-handed and in their late teens or early twenties (reflecting the current demographics of Psychology undergraduate courses).

Apparatus

The experiments took place in a small, darkened room that contained a single table and chair. On the table was a PC that ran a program equipped with millisecond timers. Stimuli were displayed on a Mitsubishi 67tx 19-inch colour monitor (1024 × 768 @ 100 Hz) and all reaction times (RTs) and mistakes were recorded to a data file.

The foot response device: A wooden board with two inlaid micro-switches fixed approximately 60cm apart, was located on the floor directly under the monitor. Hinged Perspex flaps covered the micro-switches, allowing the balls of the feet to rest on them. The back of the board was raised from the floor at an angle of approximately 25°, allowing the feet to rest at a comfortable angle.

Materials

A blue background with the centrally placed words 'Get Ready' served as the inter-trial stimulus. The stimulus set consisted of 44 colour digital photographs (640 × 400 dpi) of common household objects. 22 objects were kitchen-related and 22 objects were garage-related (see Figure 3.2). The objects were manipulated in two horizontal orientations (leftwards and rightwards) and two locations (left and right). In total there were 44 (objects) × 2 (horizontal object orientations) × 2 (object locations) = 176 different images. See Figure 3.3 for an illustration of the stimulus set and stimulus properties associated with one kitchen and one garage object.

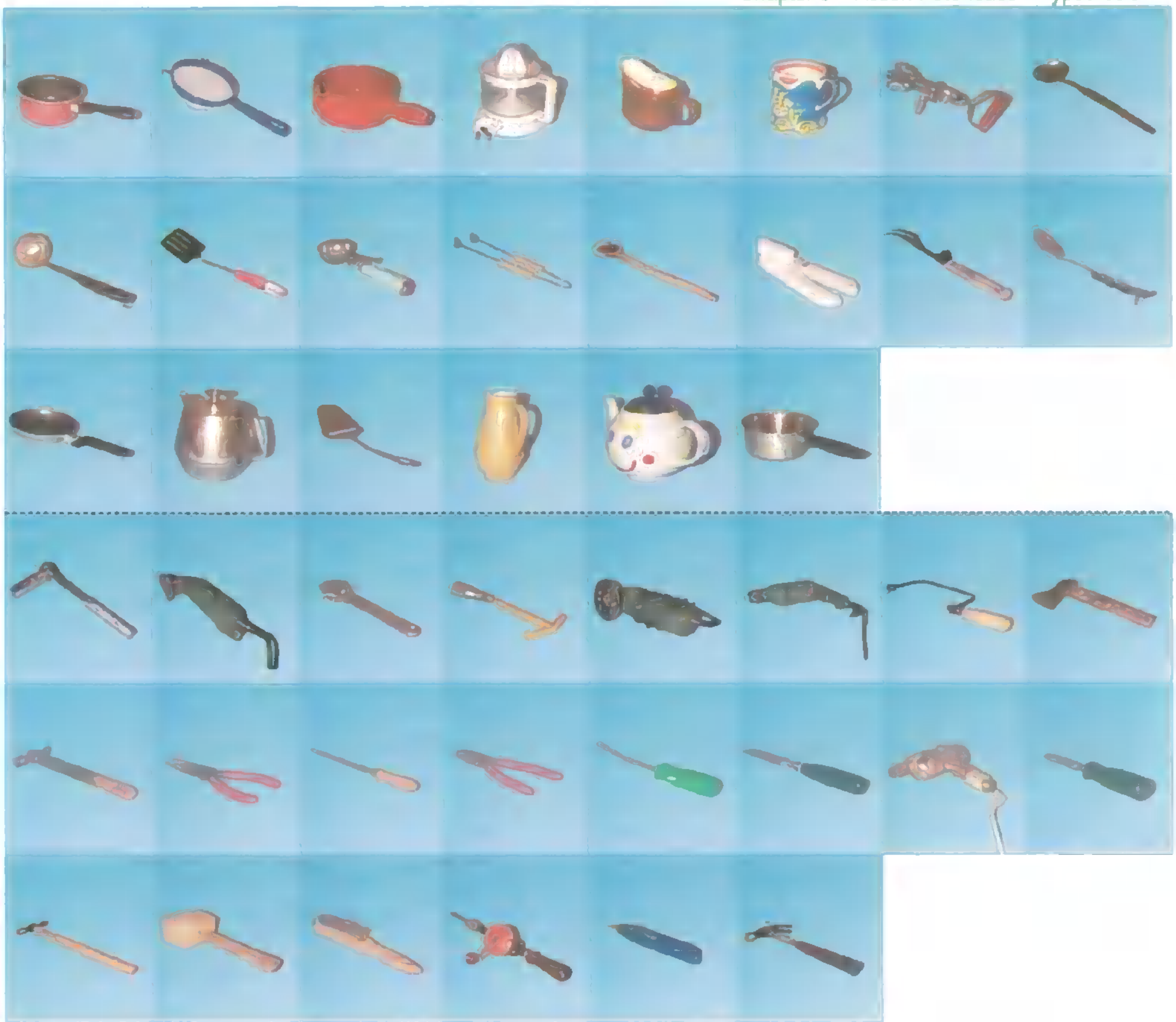


Figure 3.2 44 objects used in Experiment 3.1 (and the study by Symes, 1999). Above the dotted line are kitchen objects, below the dotted line are garage objects. The objects are only shown in the rightwards horizontal orientation

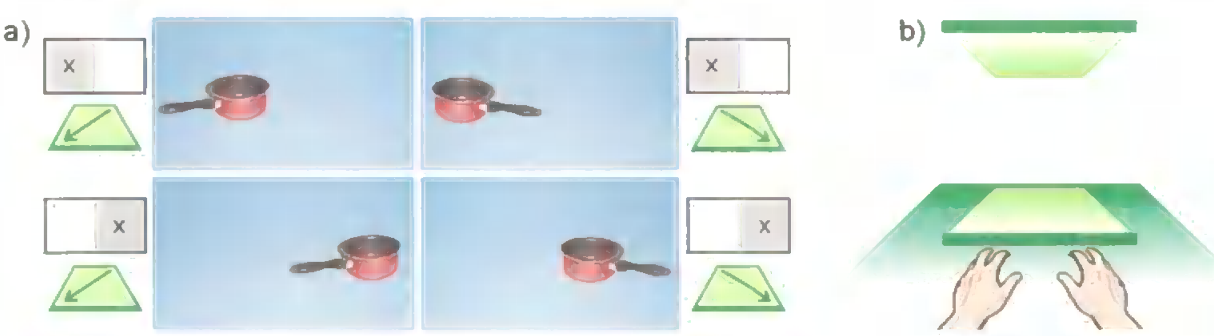


Figure 3.3 A definition of stimulus attributes. a) An example object shown in two locations and two horizontal orientations. The icons illustrate the screen location of the object (grey icons) and its horizontal orientation (green icons). b) This illustration depicts the X-Z plane (the plane in which the objects are oriented). The thick green lines represent an arbitrary reference point in this plane (located at the leading edge of the plane, which is nearest to the viewer in space). This reference point allows the use of arrowheads in the X-Z plane icons (which always point towards the reference point). Thus arrowheads in the icons of a) that point left define the object as being oriented leftwards in the X-Z plane, and arrowheads that point right define the object as being oriented rightwards in the X-Z plane.

Design

The two dependent variables were RTs and mistakes. The three within subjects independent variables were horizontal object orientation (leftwards, rightwards), object location (left, right) and foot of response (left, right). The between subjects independent variable was mapping rule. Thus the experiment was a 2 × 2 × 2 × 2 repeated measures design, as illustrated in Table 3.1.

Table 3.1 Experimental design for Experiment 3.1. Key: mapping rule (MR), condition 1 (C1), condition 2 (C2), experimental group (G)

		MR			
		C1		C2	
Orientation	Leftwards	G_1	(n = 15)	G_2	(n = 15)
	Rightwards	G_1	(n = 15)	G_2	(n = 15)
Location	Left	G_1	(n = 15)	G_2	(n = 15)
	Right	G_1	(n = 15)	G_2	(n = 15)
Response	Left	G_1	(n = 15)	G_2	(n = 15)
	Right	G_1	(n = 15)	G_2	(n = 15)

In mapping rule: condition 1 (MR: C1) [n = 15], left foot responses were made to kitchen objects and right foot responses were made to garage objects. This 'foot of response/object category' pairing was reversed in mapping rule: condition 2 (MR: C2) [n = 15]. A practice session consisted of one block of 30 trials. The main experiment consisted of one block of 352 trials (each image was presented twice, thus 176 images × 2 = 352 trials). The order of images was randomised in one block of 352. As responses were dependent on the kitchen or garage category of the object, the independent variables of object location and object orientation were task irrelevant.

Procedure part a (general procedure)

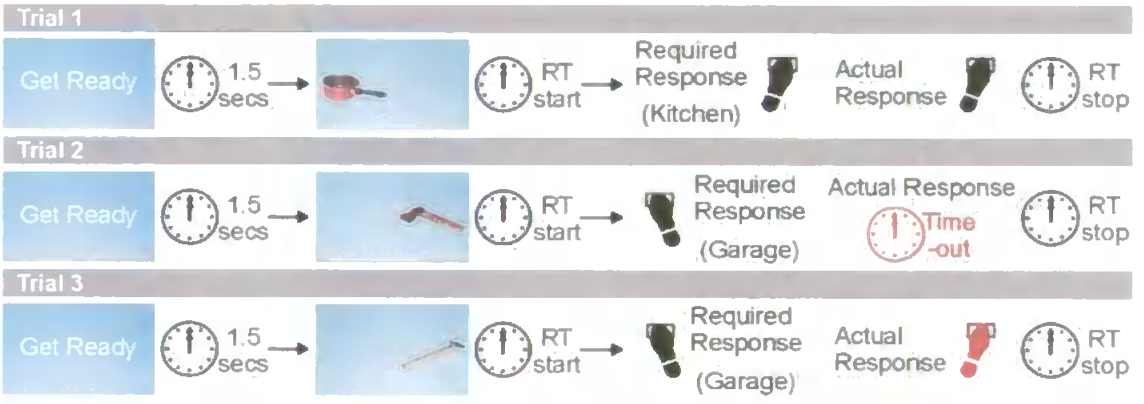
All participants were asked to read and sign a consent form informing them of their rights within the context of the ethical guidelines outlined by the British Psychological Society. In addition participants were asked to sign a form acknowledging their receipt of payment. Participants sat at the table, facing the monitor with an initial eye to screen distance of approximately 50cm. As a general instruction, participants were asked to make fast responses to stimuli, without incurring more than 10 % mistakes. Participants were told at some length that there was an ideal balance of speed and accuracy to aim for, which involved making quick responses, but not so quick that they continuously made mistakes. By the same token they were not to avoid making mistakes altogether, as this would suggest they were not responding quickly enough overall. Participants were given a practice session to familiarise themselves with the task, and then started the main experiment. All mistakes and time-outs (see below for definitions) were signalled by a beep from the computer. Keys "p" and "c" on the keyboard served to pause and continue each experiment, and were available throughout, had the participant required a rest.

Procedure part b (trial procedure)

Participants were pseudo-randomly allocated to an experimental group (Group 1- MR: C1, Group 2- MR: C2). According to their group allocation, they were instructed which foot to respond with for each object category. After completing the practice session, the main experiment began. The experimental trial procedure is outlined in Box 3.2.

Box 3.2 Trial procedure for Experiment 3.1. The clock icon depicts a millisecond timer and the shoe icon depicts a foot key press. The colour red corresponds to an incorrect response.

The schematic below depicts three typical trials for a participant assigned to MR: C2 (left responses for garage objects, right responses for kitchen objects). For each trial, the inter-trial stimulus was shown for 1.5 seconds and was then replaced with the target stimulus. A millisecond timer measured the time that the target stimulus remained on the screen. This could be until the participant made a left or right foot response, or until three seconds had passed and the trial was given time-out. Following the response (or time-out) the target stimulus was immediately replaced with the inter-trial stimulus for a new trial, thus completing the loop.



3.4.2 Results

Analytical Procedure and Summary Results

Analysis by Participants (A by P): Two subsets of data were selected from the raw data for statistical analysis. The *correct response data* consisted of the mean RTs (for each participant in each condition) of all trials that remained once the following had been removed:

a. Trials that violated the task rule (i.e. mistakes were removed).

b. Trials that exceeded a 'time-out' limit of 3 seconds (i.e. 'time-outs' were removed).

c. Trials that were two standard deviations above or below each participant's overall mean correct score (i.e. outliers were removed).

From the remaining RT data, means were calculated. These mean correct RTs served as input for the first analysis of variance (ANOVA). The *incorrect response data* was derived from the mean percentage of mistakes (see a. above) for each participant in each condition. The mean percentages of mistakes served as input for the second ANOVA. In each A by P, participants were entered as a random factor. The dependent variables were RTs and mistakes.

Analysis by Materials (A by M): Two subsets of data were selected from the raw data for statistical analysis. The *correct response data* consisted of the mean RTs (for each object in each condition) of all trials that remained once the following had been removed:

a. Trials that violated the task rule (i.e. mistakes were removed).

b. Trials that exceeded a 'time-out' limit of 3 seconds (i.e. 'time-outs' were removed).

c. Trials that were two standard deviations above or below each object's overall mean correct score (i.e. outliers were removed).

From the remaining RT data, means were calculated. These mean correct RTs served as input for the first analysis of variance (ANOVA). The *incorrect response data* was derived from the mean percentage of mistakes (see a. above) for each object in each condition. The mean percentages of mistakes served as input for the second ANOVA. In each A by M, objects were entered as a random factor. The dependent variables were RTs and mistakes.

Four repeated measures ANOVAs (located in Appendix 1) were performed on the between subjects independent variable of mapping rule (condition 1: kitchen objects/ left response, condition 2: garage objects/ right response), and the within subjects independent variables of X-Z object orientation (leftwards, rightwards), object location (left, right), and foot of response (left, right). The dependent variables were RTs (the first two ANOVAs; A by P and A by M) and mistakes (the second two ANOVAs; A by P and A by M). The results for Experiment 3.1 are summarised in Table 3.2. Key results are reported in the text and remaining results are reported in Appendix 2.

Table 3.2 Main effects and interactions reported in Experiment 3.1. Key: analysis by participants (A by P), analysis by materials (A by M), mean RTs (black), mean mistakes (red), statistical significance status (approaching, yes, no). ✓ depicts results of key theoretical interest.

Result no.	Source	A by P		A by M	
3.1.1✓	X-Z object orientation	Yes	No	Yes	No
3.1.2	Response × Mapping rule	No	Yes	Yes	Yes
3.1.3	Object location × Mapping rule	No	Yes	No	No
3.1.4✓	Object Location × Response	Yes	Yes	Yes	Yes
3.1.5✓	X-Z object orientation × Response	App	No	Yes	No
3.1.6	Object location × Response × Mapping rule	No	No	No	Yes

Main Effects [3.1.1✓]

There was a significant main effect (in both analyses) of X-Z object orientation in RTs (A by P: [F (1, 28) = 11.675, p < 0.005], A by M: [F (1, 42) = 6.511, p < 0.05]), but not in mistakes (A by P: [F (1, 28) = 0.732, p > 0.1], A by M: [F (1, 42) = 1.212, p > 0.1]). Mean RTs were 13 ms (A by P) and 7 ms (A by M) faster for objects oriented rightwards rather than leftwards. This main effect revealed that regardless of which foot (left or right) responses were made with, there was an advantage for rightwards-oriented objects. It can be speculated that the predominantly right-handed participants were more perceptually sensitive to objects that were oriented rightwards, by virtue of their long history of interacting with handled objects predominantly with their right hands. This is obviously a major speculation that would require considerably more evidence than is provided here to support it. Nevertheless, it is an intriguing possibility with major theoretical implications.

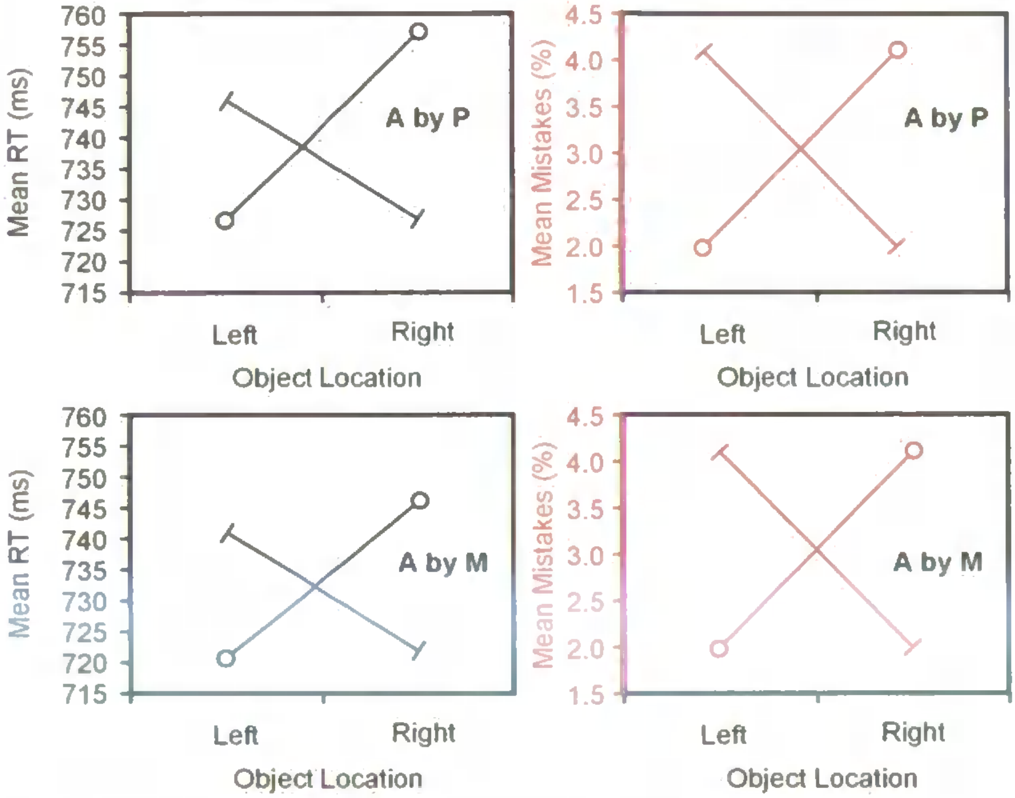
Means and standard errors for this main effect [3.1.1] are shown in Table 3.3.

Table 3.3 Mean RTs (ms) and standard errors (SE) for significant main effect in Experiment 3.1.

X-Z Orientation	A by P		A by M	
[3.1.1]	✓ (ms)	SE	✓ (ms)	SE
Leftward	746	22	736	7
Rightward	733	20	729	7

Two-Way Interactions [3.1.4✓]

There was a significant interaction between object location and foot of response, in both RTs (A by P: [F (1, 28) = 29.497, p < 0.001], A by M: [F (1, 42) = 60.580, p < 0.001]) and mistakes (A by P: [F (1, 28) = 20.351, p < 0.001], A by M: [F (1, 42) = 25.136, p < 0.001]) (see Figure 3.4). For <u>left located objects</u>, mean RTs were 19 ms (A by P) and 20 ms (A by M) faster (and mean mistakes were 2.1 % (A by P and A by M) fewer) for left rather than right foot responses. For <u>right located objects</u>, mean RTs were 30 ms (A by P) and 24 ms (A by M) faster (and mean mistakes were 2 % (A by P and A by M) fewer) for right rather than left foot responses. This pattern resembled a straightforward spatial stimulus-response compatibility effect (e.g. a Simon Effect).



KEY

Left response
Right response

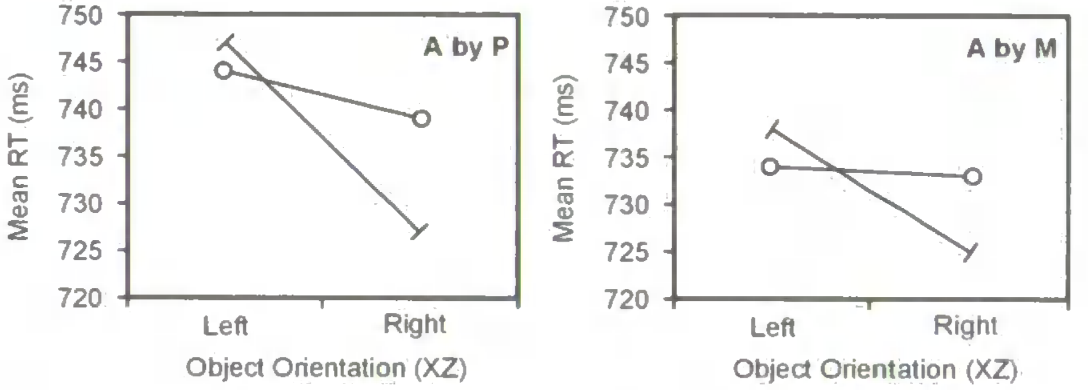
MEANS TABLE

		A by P				A by M			
Loc	Resp	ms	SE	%	SE	ms	SE	%	SE
L	L	727	21	2.0	0.4	721	7	2.0	0.5
L	R	746	21	4.1	0.7	741	8	4.1	0.8
R	L	757	22	4.1	0.5	746	8	4.1	0.7
R	R	727	21	2.1	0.4	722	7	2.1	0.4

Figure 3.4 (A by P and A by M) Mean RTs (black lines) and mean mistakes (red lines) as a function of foot of response and object location

Two-Way Interactions [3.1.5 ✓]

There was a significant interaction between X-Z object orientation and foot of response in RTs (A by P: [F (1, 28) = 4.060, p = 0.054], A by M: [F (1, 42) = 4.732, $p < 0.05$]) but not in mistakes (A by P: [F (1, 28) = 0.115, $p > 0.50$], A by M: [F (1, 42) = 0.147, $p > 0.5$]) (see Figure 3.5). For objects oriented leftwards, mean RTs were 3 ms (A by P) and 4 ms (A by M) faster for left rather than right foot responses. For objects oriented rightwards, mean RTs were 12 ms (A by P) and 8 ms (A by M) faster for right rather than left responses. This interaction revealed an advantage when horizontally orientated household objects were compatible with foot responses, supporting the notion of abstract action-oriented representations (e.g. 'common codes') that are sufficiently under-specified as to influence a range of compatible responses, so long as those responses have been 'set up' by a physical context.[35]



KEY

- Left response (line with circle markers)
- Right response (line with cross markers)

MEANS TABLE

		A by P				A by M			
Ori	Resp	ms	SE	%	SE	ms	SE	%	SE
L	L	744	21	2.8	0.5	734	8	2.8	0.6
L	R	747	23	3.0	0.6	738	8	3.0	0.6
R	L	739	21	3.3	0.5	733	7	3.3	0.6
R	R	727	20	3.2	0.5	725	7	3.2	0.5

Figure 3.5 (A by P and A by M) Mean RTs as a function of foot of response and X-Z object orientation

3.4.3 Discussion

Experiment 3.1 was a replication of a study by Symes (1999); a study that reported facilitation of left and right hand key presses that were compatible with the horizontal orientations and locations of a series of objects. The purpose of the replication was simply to establish whether foot responses would produce similar compatibility effects as those found for hands. Four Action Specificity Hypotheses were generated: 1- a specific action property is afforded that is exclusive to one action; 2- a primitive action property is afforded that is common to many actions; 3- a specific action property is maximally

[35] A direct statistical comparison of this Experiment 3.1 with Experiment 1 of Symes (1999) did not reveal a significant difference between the interaction of X-Z object orientation × hand of response (found in the Symes, 1999 Experiment 1) and the interaction of X-Z object orientation × foot of response (reported above). It therefore appears that hand and foot responses do not behave differently with respect to horizontal object orientation, further supporting the notion of 'common codes'. The statistical comparison between experiments has not been reported for reasons of brevity, however the ANOVA is located in Appendix 1.

afforded but other action properties are to a lesser extent activated; 4- a range of actions can be afforded by virtue of being physically 'set up' by task parameters.

The most important result relating to the orientation of an object [3.1.5✓] revealed the facilitation of compatible foot responses (reflected in RTs) in a manner similar to those effects found for hand responses used by Symes, 1999 (and Tucker and Ellis, 1998). This finding did not support Action Specificity Hypothesis 1 (which proposed that a specific action property is afforded that is exclusive to one action), but instead provided some support for Action Specificity Hypothesis 2. Here, an object property (e.g. orientation) might afford a primitive left or right action property that is a common component to many different actions. In addition, this finding is in keeping with Action Specificity Hypothesis 4, whereby an action that is 'set up' (i.e. partially programmed or soft-assembled) will heighten perceptual awareness (in terms of attention) to visual properties of the object (in this case orientation) that become relevant to that action. In turn that visual property will be more likely to afford the same properties of an action that have been 'set up' [36].

In finding support for Action Specificity Hypothesis 2, there is no need to accept that the 'setting up' of actions played a part in the interaction between foot of response and object orientation reported in Experiment 3.1. The commonality of visuomotor primitives to a range of actions is in itself a sufficient (if somewhat under-specified) explanation of the data. Indeed, the APH does not accept that the 'setting up' of actions contributed to their compatibility effects. Thus Ellis and Tucker (2000, p. 466) explained with respect to their object size compatibility effects (return to Figure 3.1 part C),

> "It is true that an aspect of the object is relevant to a viewer's current behaviour. He/she is after all making compatible/incompatible responses. Our point is that a viewer is being affected by grasp-related properties of an object, which he/she has no intention of grasping".

[36] Of course an arbitrary coding account such as the DO model would also predict the results obtained. However, as has been argued earlier, this interpretation loses credibility if an embodied approach to cognition is accepted.

In other words, Ellis and Tucker (2000) are claiming that their compatibility effects *do not* reflect, in part, an influence of the actions that are 'set up', (such as a power grip that is 'set up' by holding a cylindrical response device *in a power grip*). They appear to be claiming instead that this action (the power grip) is the afforded action regardless of any intention to grasp the object (and crucially also, regardless of any intention to grasp the power grip response device). Ironically however, participants *do* have an intention to grasp the power grip response device (and in Experiment 3.1, to press a key with a particular foot), precisely because the task demands it. This fact exposes something of a vicious cycle in the reaction-time experiment approach. The response that is being made is often designed to mimic a real-world action (e.g. a power grip or a reach), and the inferences drawn concern an affordance for this type of action. However, as a consequence it can only ever be speculated that the effects produced relate to an underlying affordance for the said action, rather than the influence implicitly involved in being intentionally and physically prepared to make that same action. There is of course no reason why *both* influences should not be at play- indeed a perception-action loop account (see Chapter 1) would make exactly this claim.

3.5 General Discussion

If the notion of a perception-action loop is taken seriously, then it is clear that the influences of intentions and physical constraints involved in a task should not be ignored. Fortunately, accepting this does not oblige one to get bogged down with all the complexities of a dynamic perception-action loop (which as has been argued previously, can lead to inscrutability). In justifying this claim, it is helpful to discuss an approach that Clark (1997, p. 104) refers to as the "catch and toss" approach. Clark (1997) suggested that the "catch and toss" approach is a sensitive and canny version of componential explanation[37]. Here, the environment is treated as a source of inputs to the thinking brain (a dichotomy that the Enactive Approach rejects). Thus the world tosses inputs to the brain and the brain catches these inputs and tosses actions back. That this view applies to the APH is particularly apparent when Ellis and Tucker (2000, p. 466) suggest that, "...a viewer is being affected by grasp-related properties of an object". Thus the world tosses inputs to the brain (e.g. grasp-related visual properties of an object), and the brain catches these inputs and tosses actions back (e.g. elements of a power grip are automatically potentiated).

This approach is nevertheless sympathetic to an embodied perspective, and appreciates the dynamics of environment-agent interactions without committing to a dynamical systems theory approach. According to Clark (1997, p.466) it recognises the multiple and complex ways in which 'inner jobs' can be simplified by means of real-world structure, bodily dynamics and active interventions in the world. Clark (1997) offered animate vision as an example (see Chapter 1 for discussion), whereby low-resolution visual input can lead to real-world actions (e.g. head or eye movements) that in turn generate more suitable input for higher-resolution processing. Interestingly, because this appreciation of the dynamic agent-environment relationship is grossly oversimplified, it consequently allows for a componential explanation. As was argued in section 3.3, this can be advantageous.

Somewhat unsatisfactorily however, Ellis and Tucker (2000) only appear to commit to one half of the "catch and toss" approach, and therefore might be described as "tossers". On occasion, the APH appears to uphold the traditional temporal ordering of an 'input -> output' relationship by only arguing that inputs (e.g. visual attributes such as object orientation or object size) are caught and then outputs are tossed back (e.g. potentiated elements of a reach or grasp action). They have not acknowledged that actions can be tossed (i.e. the 'setting up' of a power grip or a hand for reaching) which influences the

[37] According to Clark (1997), componential explanation explains the capacities of an overall system by addressing the capacities and roles of its components. In short it is a reductionist approach. The APH (and the experiments in this thesis) essentially aims to provide a componential explanation of the vision-action system by identifying the capacities and roles of its components (primarily, how components of actions are influenced by components of visual inputs).

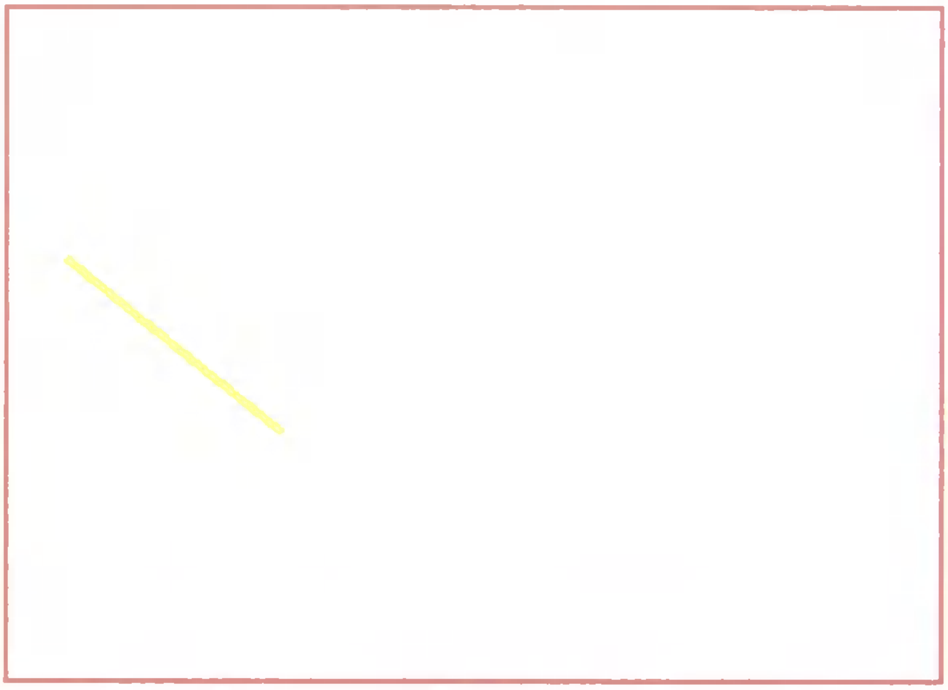
kind of inputs that are caught (e.g. attention is directed, or perceptual sensitivity is heightened, to the action-relevant size or orientation of an object).

The specificity of visual attributes

The discussion of Experiment 3.1 has concentrated on the specificity of properties of *actions* that might be afforded by properties of an object. It is equally important to address the specificity of *visual attributes* (visually perceivable properties of an object) that might afford actions. It is apparent from the stimulus set of Experiment 3.1 (return to Fig. 3.1) that each object had various features that contributed to its orientation. Thus a screwdriver had one horizontal axis of elongation whereas a hammer had two. A jug on the other hand had as its principal axis, a vertical axis of elongation. Furthermore all objects were functional objects with handles that carried connotations for action, and in each case the handle was pointed towards a particular side of the screen (i.e. towards a particular side of the viewer's body). It is not clear then, in using photographs of real-world objects, what property or properties of orientation might carry the most relevance for left-right actions. In short, what visual attribute or attributes influence the outcome of orientation-compatibility effects?

A more carefully controlled stimulus set might consist of artificial objects that vary along one or two specific dimensions only. In using artificial objects, the influences of particular object properties could be examined in relative isolation, thus allowing a systematic examination of which specific properties of an object's orientation might afford left-right actions. The next two experimental chapters adopt this approach by examining a range of left-right response types (thus continuing to investigate action specificity) that are made to a series of artificially constructed objects.

4. Two-dimensional (2D) object orientation



Contents

4.1 Experimental Hypotheses and Overview

Objective 2: To test for orientation-action compatibility effects associated with diagonal two-dimensional lines, thus exploring the possibility that a specific visual attribute might afford left-right actions; namely the angle of an object's X-Y axis. Using these simple stimuli, different left-right response types are used in order to test whether any compatibility effects are specific to hands, or viable for a range of actions.

It was argued in Chapter 3 that the orientation-action compatibility effects that Tucker and Ellis (1998) interpreted as evidence for micro-affordances did not distinguish between a number of possibilities, which included the following:

Firstly, if these effects reflected the automatic potentiation of left-right actions associated with purely visual attributes of an object (possibly through activating a 'default representational setting' that is abstracted from viewing an oriented object); then one must ask what these visual attributes are.

Secondly, there is the possibility that the motor components of these visual attribute-related affordances are abstract or primitive enough to influence any number of compatible responses, particularly if these responses are 'set up' in the first place by the physical context of the task. Experiment 3.1 provided some evidence supporting this notion.

Thirdly, it is of interest how the role of a currently exercised behavioural activity might give an object an 'activity-based' or 'functional' affordance (that might modulate an already existing default representational setting).

The three experiments in this chapter addressed the first two possibilities by examining how different left-right response types behaved with respect to simplistic artificial objects. In addressing the specificity of left-right actions afforded, the four Action Specificity Hypotheses generated in the previous chapter remained under investigation (1- a specific action property is afforded that is exclusive to one action; 2- a primitive action property is afforded that is common to many actions; 3- a specific action property is maximally afforded but other action properties are to a lesser extent activated; 4- a range of actions can be afforded by virtue of being physically 'set up' by task parameters). In addressing the specificity of visual attributes that afford left-right actions, the following hypothesis was under investigation:

Visual Attribute Hypothesis 1: The most basic property of an object's orientation (its primary axis of elongation in the X-Y plane) is a specific visual attribute that affords left-right actions. Facilitation might occur for left or right responses that are compatible with this X-Y orientation.

In testing Visual Attribute Hypothesis 1, Experiments 4.1-4.3 used as an abstract visual stimulus the most basic property of an object's orientation, namely its primary axis of elongation in the X-Y plane. Thus two diagonal lines (one oriented at 45° from the perpendicular, the other its horizontal mirror image) were used to explore the possibility that this basic dimension of orientation might afford left-right actions. Because responses were made to the colour of the 2D diagonal lines, the X-Y orientation of these lines was task irrelevant. Consequently it was assumed that any orientation-action compatibility effects obtained would reflect a goal-independent automatic activation of responses. The results consistently failed to demonstrate performance-related benefits associated with the task-irrelevant X-Y orientation of a 2D line. This was in spite of manipulations that varied the ease of colour discrimination and manipulations that varied the critical stimulus onset.

In testing the four Action Specificity Hypotheses, hand responses and foot responses were made to the same 2D stimuli. The results consistently failed to demonstrate performance-related benefits associated with the task-irrelevant X-Y orientation of a 2D line, regardless of whether hand or foot responses were made.

It was concluded that Experiments 4.1-4.3 did not support Visual Attribute Hypothesis 1, where it was suggested that the most basic visual attribute underlying an object's orientation (i.e. its primary axis of elongation in the X-Y plane) was a visual attribute that might afford left-right actions. Furthermore, no conclusions could be drawn regarding the four Action Specificity Hypotheses, owing to the generic lack of a compatibility effect associated with the X-Y plane.

4.2 Experiment 4.1

In in using two-dimensional diagonal lines as stimuli, varying their location, and comparing foot responses with hand responses; Experiment 4.1 served as a broad one-shot experiment that addressed many of the issues raised by Experiment 3.1. Thus it was tested whether the orientation in the X-Y plane of an abstract stimulus (that carried no connotations of object function or visual saliency) would reveal itself as a basic visual attribute that might afford left-right actions (Visual Attribute Hypothesis 1). If so, perhaps this was the action-relevant visual attribute that had been extracted from the real visual objects used in Experiment 3.1. Furthermore, it was tested whether object location would again be shown to have a separate influence on responses (as was the case in the Symes, 1999 study). Finally, it was tested whether foot and hand responses would behave differently; or not, as was demonstrated in Experiment 3.1.

4.2.1 Method

Participants

As Experiment 3.1 (undergraduate volunteers etc.), but 32 participants were used.

Apparatus

As Experiment 3.1 (small darkened room, PC etc.), but two response devices were used (one for hands and one for feet). A gentle downward press of a response device depressed a micro-switch that registered the response.

1. *The hand response device:* A wooden board with two inlaid micro-switches fixed approximately 40cm apart, was located on the table directly in front of the monitor.
2. *The foot response device:* As Experiment 3.1.

Materials

The screen background was a light grey colour at all times. The inter-trial stimulus was a centrally placed black circle. The stimulus set was based on two computer-generated diagonal lines (a 2D vertical line rotated 45° clockwise about its centre, one clockwise and the other anti-clockwise). Both diagonal lines were reproduced in two colours (green and yellow), resulting in a stimulus set of four lines. These lines were displayed in three screen positions (left, centre and right). See Figure 4.1 for an illustration of the stimulus set and stimulus properties.

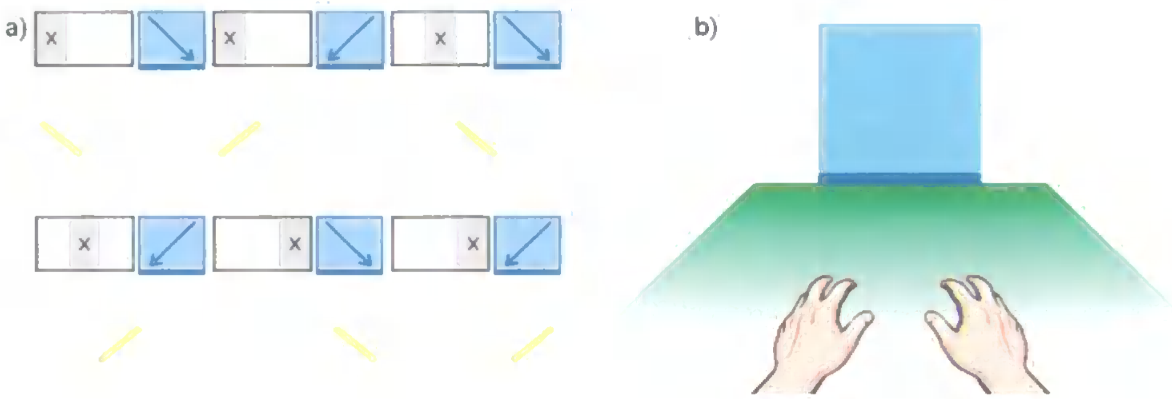


Figure 4.1 a) Stimulus set for Experiment 4.1, showing all combinations of location and X-Y orientation (only yellow lines are shown). The grey icons illustrate the screen location of the line (left, centre, right) and blue icons illustrate the X-Y orientation of the line. b) This illustration depicts the X-Y plane (the plane in which the lines are oriented). The thick blue line represents an arbitrary reference point in this plane (located at the bottom edge of the plane, which is nearest to the viewer's hands in space). This reference point allows the use of arrowheads in the X-Y plane icons (which always point towards the reference point). Thus arrowheads in the icons of a) that point left define the object as being oriented leftwards in the X-Y plane, and arrowheads that point right define the object as being oriented rightwards in the X-Y plane.

Design

The two dependent variables were RTs and mistakes. The four within subjects independent variables were spatial response (left, right), X-Y line orientation (leftwards, rightwards), effector (hands, feet) and line location (left, centre, right). The two between subjects independent variables were mapping rule 1 and mapping rule 2. Thus the experiment was a $2 \times 2 \times 2 \times 3 \times 2 \times 2$ repeated measures design, as illustrated in Table 4.1.

In mapping rule 1: condition 1 (MR1: C1) [n = 16], responses were made with hands for the first block of the experiment and feet for the second block. The order of response effector was reversed in mapping rule 1: condition 2 (MR1: C2) [n = 16]. In mapping rule 2: condition 1 (MR2: C1) [n = 16], left spatial responses were made to green lines and right spatial responses were made to yellow lines. The 'spatial response-colour pairing' was reversed in mapping rule 2: condition 2 (MR2: C2) [n = 16]. A practice session consisted of 20 trials, divided into two blocks of 10 trials (allowing for response effector changeover). The main experiment consisted of 720 trials, divided into two blocks of 360 trials (allowing for response effector changeover). For each block, each incidence of line was presented 30 times (2 blocks × 4 lines × 3 locations × 30 presentations = 720 trials). The order of lines was randomised within each block. As responses were dependent on line colour, the independent variables of line location and X-Y line orientation were task irrelevant.

Table 4.1 Experimental design for Experiment 4.1. Key: mapping rule 1 (MR1), mapping rule 2 (MR2), condition 1 (C1), condition 2 (C2), experimental group (G)

				MR1	
				C1	C2
MR2	C1	Effector	Hands	G_1 (n = 8)	G_2 (n = 8)
			Feet	G_1 (n = 8)	G_2 (n = 8)
		Location	Left location	G_1 (n = 8)	G_2 (n = 8)
			Right location	G_1 (n = 8)	G_2 (n = 8)
		Orientation	Leftwards orientation	G_1 (n = 8)	G_2 (n = 8)
			Rightwards orientation	G_1 (n = 8)	G_2 (n = 8)
		Response	Left spatial response	G_1 (n = 8)	G_2 (n = 8)
			Right spatial response	G_1 (n = 8)	G_2 (n = 8)
	C2	Effector	Hands	G_3 (n = 8)	G_4 (n = 8)
			Feet	G_3 (n = 8)	G_4 (n = 8)
		Location	Left location	G_3 (n = 8)	G_4 (n = 8)
			Right location	G_3 (n = 8)	G_4 (n = 8)
		Orientation	Leftwards orientation	G_3 (n = 8)	G_4 (n = 8)
			Rightwards orientation	G_3 (n = 8)	G_4 (n = 8)
		Response	Left spatial response	G_3 (n = 8)	G_4 (n = 8)
			Right spatial response	G_3 (n = 8)	G_4 (n = 8)

Procedure part a (general procedure)

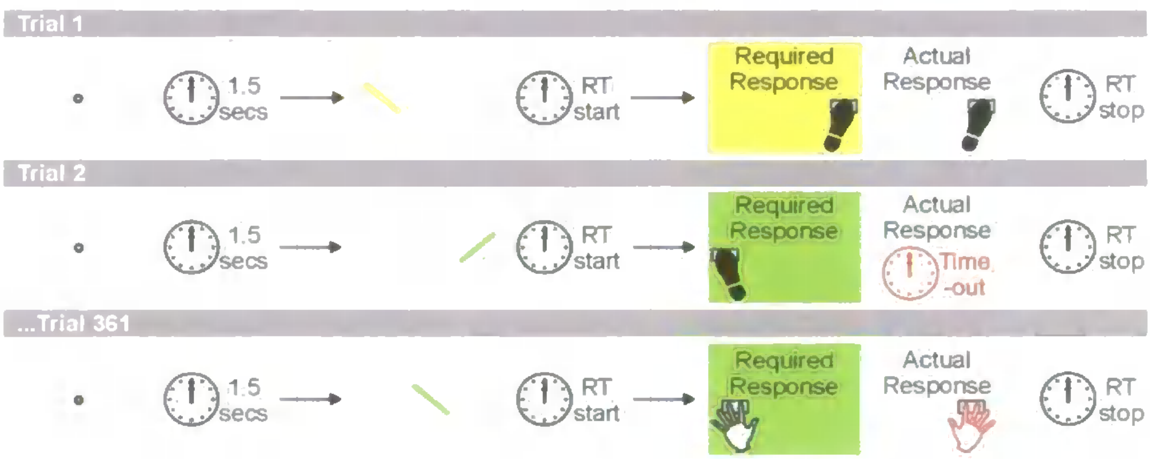
As Experiment 3.1 (consent forms, general instruction of fast and accurate responses etc.).

Procedure part b (trial procedure)

Participants were pseudo-randomly allocated to an experimental group (Group 1- MR1: C1, MR2: C1; Group 2- MR1: C2, MR2: C1; Group 3- MR1: C2, MR2: C1 and Group 4- MR1: C2, MR2: C2). According to their group allocation, they were instructed what order of response effector to use and which spatial response to make to each line colour. The effector changeover associated with mapping rule 1 was signalled on the screen halfway through the experiment, and participants took a short break before resuming the experiment with the newly assigned effectors. After completing the practice session (20 trials), the main experiment began. The trial procedure is outlined in Box 4.1.

Box 4.1 Trial procedure for Experiment 4.1. The clock icon depicts a millisecond timer, the shoe icon depicts a foot response and the hand icon depicts a hand response. The colour red corresponds to an incorrect response.

The schematic below depicts three typical trials for a participant assigned to MR1:C2 (foot responses first half, hand responses second half) and MR2:C1 (left responses for green, right responses for yellow). For each trial, the inter-trial stimulus was shown for 1.5 seconds and was then replaced with the target stimulus. A millisecond timer measured the time that the target stimulus remained on the screen. This could be until the participant made a left or right (hand or foot) response, or until three seconds had passed and the trial was given time-out. Following the response (or time-out), the target stimulus was immediately replaced with the inter-trial stimulus for a new trial, thus completing the loop.



4.2.2 Results

Analytical Procedure and Summary Results

Analyses were as described for Experiment 3.1 (correct and incorrect response data sets etc.), but there was only an analysis by participants. Two repeated measures ANOVAs (located in Appendix 1) were performed on the between subjects independent variables of mapping rule 1 and mapping rule 2, and the within subjects independent variables of effector, spatial response, line location and X-Y line orientation. Participants were entered as a random factor, and the dependent variables were RTs (the first ANOVA) and mistakes (the second ANOVA). The results for Experiment 4.1 are summarised in Table 4.2. Key results are reported in the text and remaining results are reported in Appendix 2.

Table 4.2 Main effects and interactions reported in Experiment 4.1. Key: statistical significance status (approaching, yes, no). ✓ depicts results of key theoretical interest.

Result no.	Source	Correct Resp.	Incorrect Resp.
4.1.1	Line location	Yes	Yes
4.1.2	Effector	Yes	Yes
4.1.3	Effector × MR 1	App	No
4.1.4 ✓	X-Y line orientation × Response	No	No
4.1.5	Line location × X-Y line orientation	No	Yes
4.1.6	Response × MR 1	Yes	No
4.1.7 ✓	Line location × Response	Yes	Yes
4.1.8 ✓	Effector × X-Y line orientation × Response	No	No
4.1.9	Line location × X-Y line orientation × MR1	Yes	No
4.1.10 ✓	Effector × Line location × Response	Yes	Yes
4.1.11 ✓	Line location × X-Y orientation × Response	No	No
4.1.12 ✓	Effector × Line location × X-Y orientation × Response	No	No
4.1.13	Effector × X-Y line orientation × MR1 × MR2	Yes	No
4.1.14	Line location × X-Y line orientation × Response × MR1	No	Yes

Two-Way Interactions [4.1.4 ✓]

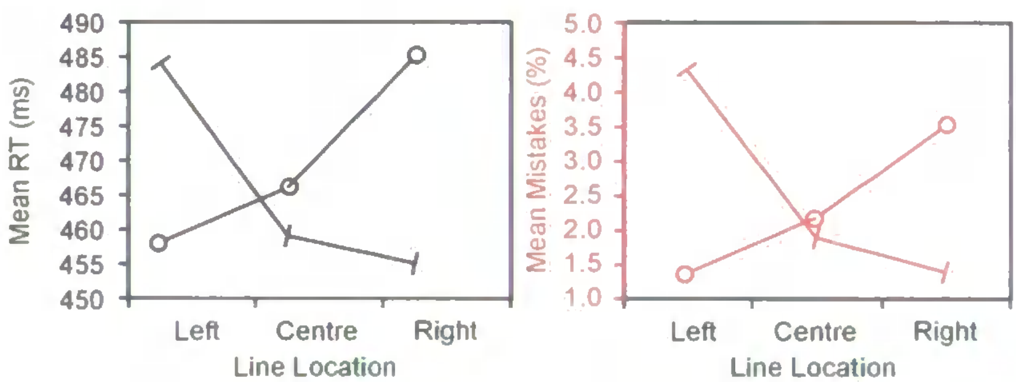
There was no significant interaction between X-Y line orientation and spatial response (i.e. collapsed across hand and foot key presses), in either RTs [F (1, 28) = 2.004, $p > 0.10$] or mistakes [F (1, 28) = 0.004, $p > 0.50$]. This suggested that the X-Y orientation of a 2D line did not have any associated performance-related benefits for spatial responses. See Table 4.3 for associated means.

Table 4.3 Mean RTs (ms), mistakes (%) and standard errors (SE) for result [4.1.4 ✓]

Ori	Res	ms	SE	%	SE
L	L	469	10	2.5	0.5
L	R	467	10	2.7	0.4
R	L	470	10	2.2	0.3
R	R	465	10	2.4	0.4

Two-Way Interactions [4.1.7 ✓]

There was a significant interaction between line location and spatial response in both RTs [F (2, 56) = 106.070, $p < 0.001$] and mistakes [F (2, 56) = 27.492, $p < 0.001$] (see Figure 4.2). For left located lines, mean RTs were 26 ms faster (and mean mistakes were 2.9 % fewer) for left rather than right spatial responses. For centrally located lines, mean RTs were 7 ms faster (and mean mistakes were 0.3 % fewer) for right rather than left spatial responses. For right located lines, mean RTs were 30 ms faster (and mean mistakes were 2.1 % fewer) for right rather than left spatial responses. This pattern resembles a straightforward Simon Effect.



KEY

—o— Left response

—+— Right response

MEANS TABLE

Loc	Res	ms	SE	%	SE
L	L	458	10	1.4	0.2
L	R	484	10	4.3	0.5
C	L	466	11	2.2	0.4
C	R	459	10	1.9	0.3
R	L	485	10	3.5	0.7
R	R	455	10	1.4	0.3

Figure 4.2 Mean RTs (black) and mean mistakes (red) as a function of spatial response and line location.

Three-Way Interactions [4.1.8✗]

There was no significant interaction between effector type, X-Y line orientation and spatial response, for either RTs [F (1, 28) = 0.309, $p > 0.50$], or mistakes [F (1, 28) = 0.099, $p > 0.50$]. This suggested that the X-Y orientation of a 2D line did not have any associated performance-related benefits for either hands or feet. See Table 4.4 for associated means.

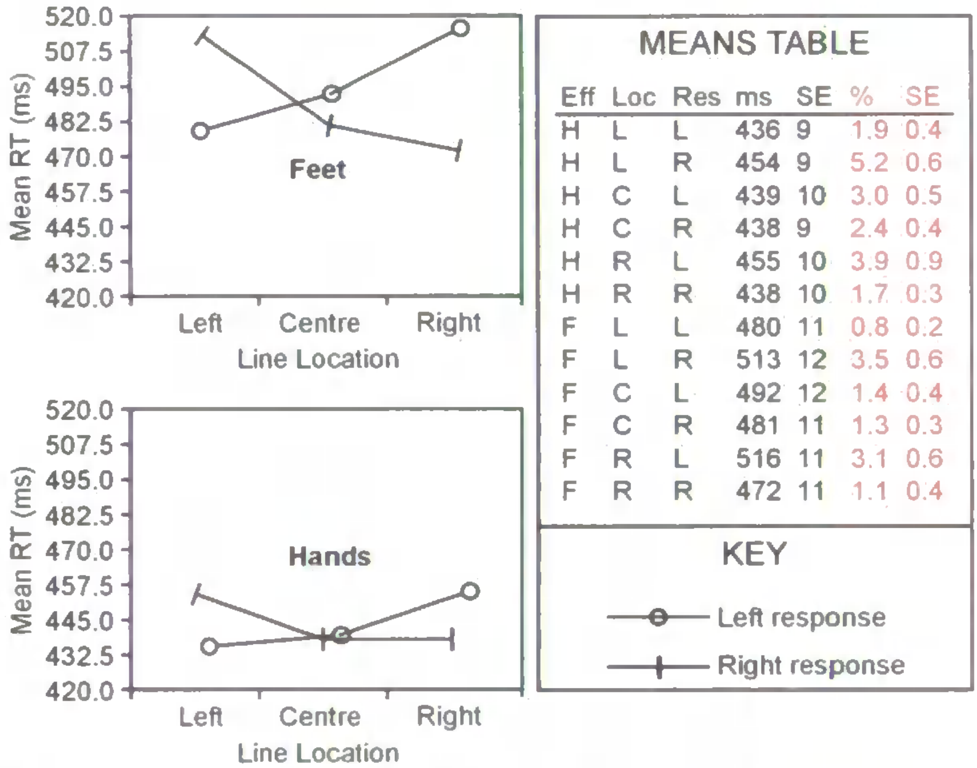
Table 4.4 Mean RTs (ms), mistakes (%) and standard errors (SE) for result [4.1.8✗]

Eff	Ori	Res	ms	SE	%	SE
H	L	L	443	9	3.1	0.6
H	L	R	444	9	3.3	0.5
H	R	L	444	9	2.8	0.5
H	R	R	443	10	2.9	0.5
F	L	L	495	11	2.0	0.4
F	L	R	490	12	2.1	0.4
F	R	L	496	11	1.5	0.3
F	R	R	487	11	1.8	0.4

Three-Way Interactions [4.1.10✗]

There was a significant interaction between effector type, line location and spatial response in RTs [F (2, 56) = 22.863, $p < 0.001$] but not in mistakes [F (2, 56) = 0.788, $p > 0.1$]. The patterns of mean RTs for feet and hands were similar to the interaction reported earlier in Figure 4.2 (which showed an interaction between line location and spatial response collapsed across effector type). The primary difference in the interactions between line location and spatial response for different effector types can be readily explained by the main effect of effector type reported earlier (where RTs were faster for hands rather than feet). This main effect can be clearly observed when comparing the two mean RT interactions in Figure 4.3.

In addition, it is notable that the effect size of the interaction for feet was almost twice as large as that of hands. This trend is somewhat unexpected considering that spatial S-R-C effects tend to reflect relative rather than absolute coding of spatial dimensions (e.g. Proctor and Reeve, 1990; Umiltà and Nicoletti, 1990). So long as a relative left-right dimensional overlap exists, according to an abstract coding account the effect sizes should be comparable for hands and feet. There is however, room for (purely) speculative interpretation when one adopts the perspective of actions that are 'set up' by the physical task. It is possibly relevant to these results that the foot response device had keys that were 20 cm farther apart than those of the hand response device. Consequently it is conceivable that the left-right dimension was more prominent or salient in the foot condition. This saliency may have impacted on the weighting of soft-assembled (or partially programmed) foot responses (thus potentially magnifying spatial S-R-C effect sizes).



MEANS TABLE

Eff	Loc	Res	ms	SE	%	SE
H	L	L	436	9	1.9	0.4
H	L	R	454	9	5.2	0.6
H	C	L	439	10	3.0	0.5
H	C	R	438	9	2.4	0.4
H	R	L	455	10	3.9	0.9
H	R	R	438	10	1.7	0.3
F	L	L	480	11	0.8	0.2
F	L	R	513	12	3.5	0.6
F	C	L	492	12	1.4	0.4
F	C	R	481	11	1.3	0.3
F	R	L	516	11	3.1	0.6
F	R	R	472	11	1.1	0.4

Figure 4.3 Mean RTs and mistakes as a function of effector type, spatial response and line location.

Three-Way Interactions [4.1.11 ✗]

There was no significant interaction between line location, X-Y line orientation and spatial response, for either RTs [F (2, 56) = 1.810, $p > 0.10$], or mistakes [F (2,56) = 0.385, $p > 0.50$]. This suggested that the X-Y orientation of a 2D line did not have any associated performance benefits when interacting with line location. See Table 4.5 for associated means.

Table 4.5 Mean RTs (ms), mistakes (%) and standard errors (SE) for result [4.1.11✗]

Loc	Ori	Res	ms	SE	%	SE
L	L	L	457	10	1.7	0.4
L	L	R	486	11	4.4	0.7
L	R	L	458	9	1.0	0.2
L	R	R	482	10	4.2	0.6
C	L	L	466	10	2.0	0.5
C	L	R	459	10	1.7	0.3
C	R	L	466	11	2.3	0.3
C	R	R	460	10	2.1	0.5
R	L	L	485	10	3.9	0.7
R	L	R	458	10	2.0	0.5
R	R	L	486	10	3.1	0.7
R	R	R	452	11	0.8	0.3

Higher Order Interactions [4.1.12✗]

There was no significant interaction between effector, line location, X-Y line orientation and spatial response, for either RTs [F (2, 56) = 0.127, $p > 0.50$], or mistakes [F (2,56) = 0.059, $p > 0.50$]. This suggested that the X-Y orientation of a 2D line did not have any associated performance benefits for hands or feet, when interacting with line location. See Table 4.6 for associated means.

Table 4.6 Mean RTs (ms), mistakes (%) and standard errors (SE) for result [4.1.11✗]

Eff	Loc	Ori	Res	ms	SE	%	SE
H	L	L	L	435	9	2.3	0.6
H	L	L	R	455	10	5.5	0.8
H	L	R	L	436	9	1.5	0.4
H	L	R	R	454	9	4.8	0.8
H	C	L	L	440	10	2.6	0.8
H	C	L	R	437	9	2.1	0.4
H	C	R	L	439	9	3.3	0.5
H	C	R	R	438	10	2.8	0.7
H	R	L	L	455	10	4.3	0.9
H	R	L	R	441	9	2.3	0.6
H	R	R	L	456	10	3.5	1.1
H	R	R	R	435	11	1.0	0.4
F	L	L	L	479	12	1.1	0.3
F	L	L	R	516	13	3.4	0.7
F	L	R	L	480	11	0.5	0.2
F	L	R	R	510	12	3.6	0.7
F	C	L	L	492	12	1.4	0.4
F	C	L	R	480	12	1.3	0.4
F	C	R	L	493	13	1.4	0.4
F	C	R	R	482	11	1.4	0.4
F	R	L	L	515	11	3.4	0.8
F	R	L	R	475	12	1.7	0.6
F	R	R	L	517	11	2.7	0.5
F	R	R	R	469	11	0.5	0.3

4.2.3 Discussion

It is of course possible that the X-Y orientation property of 2D visual stimuli simply does not afford left-right actions. As Anderson et al's (2002) recent study argued (see Chapter 3), orientation-compatible responses to 2D shapes did not appear to reflect afforded actions, but appeared instead to be derived from the directing of attention towards salient features of the shape. Thus, there was facilitation of responses when there was a salient feature to direct attention towards (e.g. the bowl component of a 2D wine glass) but none when there was no salient feature (e.g. a central circle accompanied by two equal sized dots). A diagonal 2D line similarly has no salient features. However, in terms of a possible source of affordance for left-right actions, there is a 'proximity argument'. One end of a diagonal line (or one of the dots from Anderson, Yamagishi and Karavia's, 2002, circle-and-dots stimulus) is closest to a particular hand (see Figure 4.4), and this may be the basis of an affordance for a left or right action.

Despite this proximity argument, Anderson, Yamagishi and Karavia's (2002) circle-and-dots stimulus did not facilitate responses. However, their stimulus was unusual in that it was not a uniform shape (or even a visibly interconnected collection of shapes), but rather a disconnected configuration of three separate shapes. Any one of these three shapes might conceivably be represented (in an abstract manner) as something that could be reached towards and picked up (a disc, a round pellet). Taken together however, there is no obvious way of seeing the configuration as a single uniform object that might afford left-right actions.

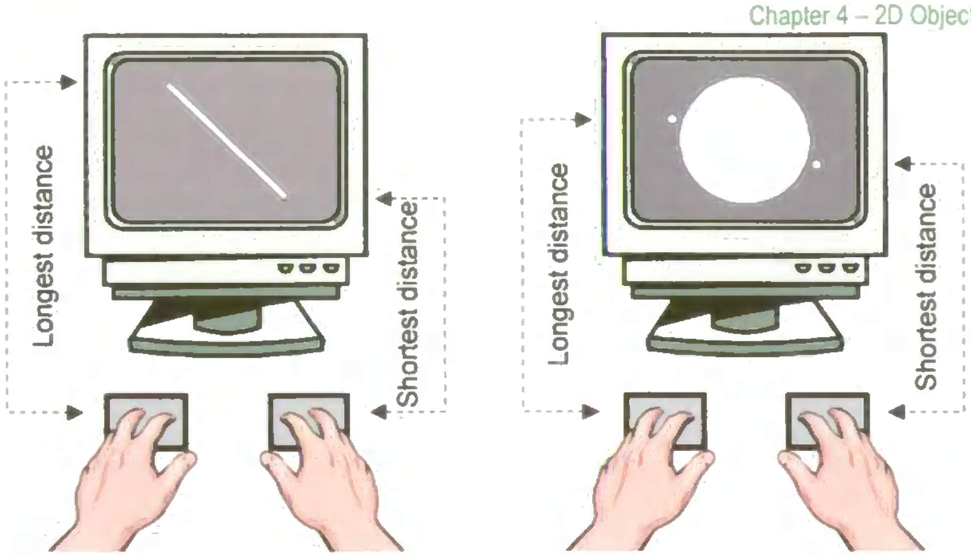


Figure 4.4 The closeness argument for 2D object-orientation. On the left the diagonal line used in Experiments 4.1 –4.3 is shown; on the right, the stimulus from Anderson et al., (2002) is shown.

A diagonal line however (e.g. as shown in Fig. 4.4 above), is a uniform object that might be represented (in an abstract manner) as something that could be reached towards and picked up (e.g. a rod of some kind). In terms of visual saliency, there is no visual cue that might favour one end of the line or the other. Similarly, in terms of an arbitrary left-right coding of the line, there is no obvious reason why the line should be coded as left rather than right or vice versa. In this light, although Experiments 4.1- 4.3 were run in ignorance of the Anderson et al's (2002) data, the stimuli employed nevertheless offered a useful test of one dimension of an object's orientation (the X-Y dimension), while controlling for salient features that might bias the directing of attention. Furthermore, in contrast to Anderson et al's (2002) study, the orientation property was task-irrelevant.

Considering the 'one-shot' approach of this experiment, it is not surprising that the numerous factors produced a wide range of significant sources of variance. Most of these sources however, were not of immediate theoretical interest. The primary aim of this experiment was to establish whether the X-Y orientation of a 2D line would facilitate performance for compatible left-right responses (Visual Attribute Hypothesis 1). The critical results, with responses collapsed across hands and feet [4.1.4↗], suggested not. Furthermore, it was of interest to see whether hands and feet behaved differently with regards to the X-Y orientation of a 2D line (Action Specificity Hypotheses 1-4). The results did not reveal any differences [4.1.8✓]. However, as neither hands nor feet were facilitated by the 2D line orientation, no useful conclusions can be drawn regarding the specificity of actions that might be afforded.

Of secondary interest was the effect of line location on responses. The Simon effect is a notoriously robust effect, and in itself, its appearance [4.1.7✓ & 4.1.10✓] was not of primary interest to the aims of this experiment. Its presence however, does serve to distinguish it from orientation-action compatibility effects; and in keeping with Symes (1999), it does appear that the two are separate and distinct phenomena. It was tentatively speculated that a more salient 'setting up' of foot responses over hand responses (possibly based on the 20 cm larger distance between left and right key locations on the foot response device) may have been responsible for the magnified effect size observed in RTs when line location interacted with spatial responses [4.1.10✓].

It would have been of theoretical interest had X-Y line orientation and responses interacted with line location (raising issues such as competing or compatible affordances from different object properties). Nevertheless, no such interactions proved to be statistically significant [4.1.11✓ & 4.1.12✓].

In conclusion, this experiment did not provide support for the hypotheses that a) the X-Y orientation of a 2D line is a visual attribute that affords left-right actions (Visual Attribute Hypothesis 1); and b) rather than an exclusive action, a range of left-right actions might be afforded (Action Specificity Hypotheses 1-4). It is possible that the highly abstract nature of the stimuli diminished the chances of finding any orientation-action compatibility effects. It was considered possible that a more difficult response criteria (that required additional attentional resources) might compensate for any adverse affects related to the abstract nature of the stimuli. The next two Experiments addressed this possibility.

4.3 Experiment 4.2

In Experiment 1 of Symes (1999), when the object category (kitchen or garage) defined left and right responses to photographs of real objects, orientation compatibility effects were found. However, when left and right responses merely categorised the same objects as red or green, no orientation compatibility effects were found (Experiment 2, Symes 1999). It can be speculated that a certain level of attention or awareness is required to derive affordances from potentially complex object properties such as orientation. Indeed, when the task requirement was simply to categorise an object's colour, it is possible that participants mostly (or only) attended to or were aware of, a patch of colour that appeared to the left or right of the screen. This perceived patch of colour may have provided sufficient information upon which to base a response, without the need to process the object in any more detail.

In Experiment 4.1, there was not a large 'patch' of colour, since the colour itself structurally defined the diagonal line (and as such there was no patch of colour, but a diagonal line of colour). Nevertheless, in terms of dedicated feature maps (e.g. a colour map that simply gets flagged when a certain perturbations of light are detected), it is still possible that the line's orientation was not processed sufficiently.

Furthermore, it is possible that the level of attention or awareness directed at the line was insufficient to derive a possible affordance for left-right actions. The level of attention or awareness needed to derive various visual-attribute based affordances is a matter of empirical investigation. The nature of the task may be influential, such that determining an object category (e.g. kitchen or garage) may well require coding the object 'as an object'. This may involve the automatic integration of features into what have been called 'object files' (e.g. Kahneman, Treisman and Gibbs, 1992). In extending this notion to action properties, Hommel and colleagues speak of 'action files' and more inclusively, 'event files' (e.g. Hommel, 1998; Hommel et al, 2001; Hommel, 2002).

It is not clear however, what is meant by 'levels of attention' or 'levels of awareness'[38]. In change-blindness studies, there is a 'Eureka' moment that occurs when one notices the change. In terms of action, Sowden and Bruyn, (2001) and Sowden et al's (2002) change-blindness studies (as discussed in 2.2.2) clearly demonstrate that motor responses are only modulated when the physical stimulus change is consciously perceived. Although the change-blindness paradigm presents a fairly extreme manipulation of a normal visual event, it does offer some insight into the level of awareness that can be needed to influence at least some classes of action.

Whether one considers the perusal of a scene in a change-blindness study (such that a change is noticed), or seeing an object 'as an object' under more natural circumstances (such that an affordance is derived), time is clearly involved to an extent. Initially at least, a considerable amount of time (up to a minute) is needed to notice a change in a change-blindness scene. Once a change has been detected however, it is immediately detected on later occasions. In the Symes (1999) study, the object categorization task of Experiment 1 ensured considerably longer RTs than those in the colour categorisation task of Experiment 2 (where no compatibility effects were found). Whatever the underlying cognitive processes that may have been at work, part of the reason colour categorisation did not produce any compatibility effects may have been because not enough time was spent looking at the objects.

[38] The terms attention and awareness are used loosely. Does awareness require attention, or vice-versa, or are they the same thing? O'Regan and Nöe, 2001 argued at length that consciousness, awareness, experience or qualia (of which they do not distinguish between) come about through currently exercising the laws of sensorimotor contingency.

Indeed, contrary to the typical finding of a rapid decay of the Simon effect (a decay which is more or less linear with increasing RTs) [39]; Tucker & Ellis (2001) reported an opposite pattern in the time course of their compatibility effects (compatibility between object size and grip type). The longer the RTs were (and hence the more time spent looking at the objects), the greater the size the compatibility effect was (again, in what appeared to be a linear fashion). Once the object disappeared from view however, the effect soon decayed.

It is therefore possible that the green and yellow colours used in Experiment 4.1 were easily discriminated (and consequently the stimuli did not need to be looked at for very long), and this short viewing time might have contributed to the lack of a compatibility effect for line orientation. This issue was addressed in Experiments 4.2 and 4.3, which used two colours (yellow and orange) that were subjectively harder to discriminate (and therefore categorise). Furthermore, stimulus onset asynchrony (SOA) was introduced, such that a grey diagonal line was presented for a short time before it changed to the colour (yellow and orange) upon which responses were based. This ensured that participants looked at the oriented line for some time before they were able to make a colour-based response towards it.

4.3.1 Method

Participants

As Experiment 3.1 (undergraduate volunteers etc.), but twenty participants took part.

Apparatus

As Experiment 3.1 (darkened room, PC etc.), but only the hand response device was used.

[39] It is assumed that an automatically generated irrelevant response code decays, perhaps because it may not be selected for an actual action. See for example, Hommel (1993, 1994a, 1994 b, 1995), and de Jong, Liang and Lauber (1994) (but see Zhang & Kornblum, 1997, for a criticism of de Jong et al's distributional analyses).

Materials

The screen background was a light grey colour. The inter-trial stimulus was a centrally placed black circle. Two diagonal lines (as used in Experiment 4.1) were reproduced in three colours (grey, orange and yellow), resulting in a stimulus set of six lines. These lines were always displayed in the centre of the screen. See Figure 4.5 for an illustration of the stimulus set and stimulus properties.

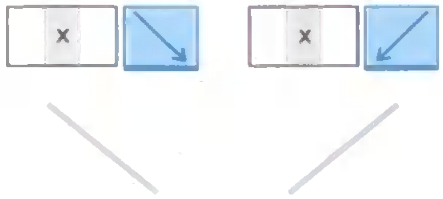


Figure 4.5 Stimulus set (lower section) for Experiment 4.2. Only the stimulus set for grey lines is shown. The icons (upper section) illustrate the screen location and X-Y orientation of the line.

Design

The two dependent variables were RTs and mistakes. The three within subjects independent variables were delay (50 ms, 100 ms), spatial response (left, right) and X-Y line orientation (leftwards, rightwards). The between subjects independent variable was mapping rule. Thus the experiment was a 2 × 2 × 2 × 2 repeated measures design (see Table 4.7).

Table 4.7 Experimental design for Experiment 4.2. Key: mapping rule (MR), condition 1 (C1), condition 2 (C2), experimental group (G)

		MR			
		C1		C2	
Delay	50 ms	G_1	(n = 10)	G_2	(n = 10)
	100 ms	G_1	(n = 10)	G_2	(n = 10)
Orientation	Leftwards orientation	G_1	(n = 10)	G_2	(n = 10)
	Rightwards orientation	G_1	(n = 10)	G_2	(n = 10)
Response	Left hand response	G_1	(n = 10)	G_2	(n = 10)
	Right hand response	G_1	(n = 10)	G_2	(n = 10)

In mapping rule: condition 1(MR: C1) [n = 10], left hand responses were made to orange lines and right hand responses were made to yellow lines. The 'hand of response - colour pairing' was reversed in mapping rule: condition 2 (MR: C2) [n = 10]. A practice session consisted of one block of 20 trials. The main experiment consisted of one block of 400 trials. Each variation of the coloured line was shown 50 times in each of the two delays (50 presentations × 4 lines × 2 delays = 400 trials). The order of coloured lines was randomised within each delay. As responses were dependent on the line colour, the independent variables of delay and X-Y line orientation were task irrelevant.

Procedure part a (general procedure)

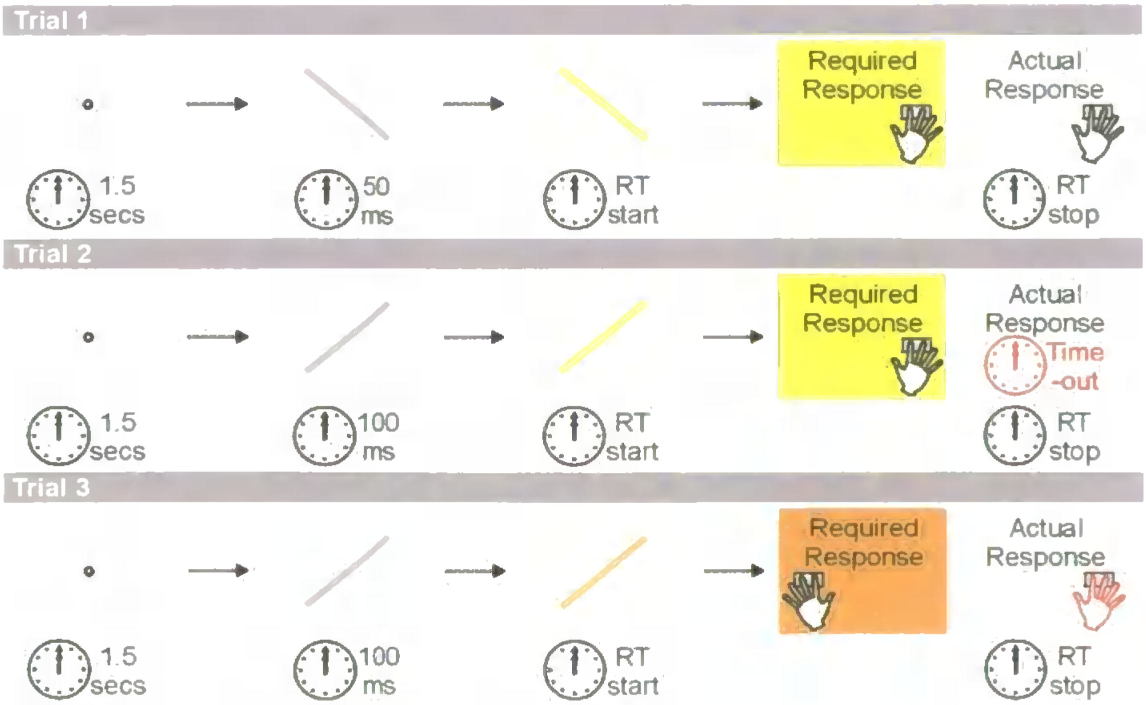
As Experiment 3.1 (consent forms, general instruction of fast and accurate responses etc.).

Procedure part b (trial procedure)

Participants were pseudo-randomly allocated to an experimental group (Group 1- MR: C1, Group 2- MR: C2). According to their group allocation, they were instructed which hand to respond with for each line colour. Participants were warned that on each trial a grey line would appear that would change colour after an unspecified period of time. Participants were instructed to respond after the grey line had changed colour. After completing the practice session (20 trials), the main experiment began. The trial procedure is outlined in Box 4.2.

Box 4.2 Trial procedure in Experiment 4.2. The clock icon depicts a millisecond timer, and the hand icon depicts a hand response. The colour red corresponds to an incorrect response.

The schematic below depicts three typical trials for a participant assigned to MR: C1 (left responses for orange, right responses for yellow). For each trial, the inter-trial stimulus was shown for 1.5 seconds and was then replaced with the delay stimulus (a grey line) that was shown for 50 or 100 ms. The delay stimulus was then replaced with the target stimulus. A millisecond timer measured the time that the target stimulus remained on the screen. This could be until the participant made a left or right hand response, or until three seconds had passed and the trial was given time-out. Following the response (or time-out) the target stimulus was immediately replaced with the inter-trial stimulus for a new trial, thus completing the loop.



4.3.2 Results

Analytical Procedure and Summary Results

Analyses were as described for Experiment 3.1 (correct and incorrect response data sets etc.), but there was only an analysis by participants. Two repeated measures ANOVAs (located in Appendix 1) were performed on the between subjects independent variable of mapping rule, and the within subjects independent variables of delay, X-Y line orientation and hand of response. Participants were entered as a random factor, and the dependent variables were RTs (the first ANOVA) and mistakes (the second ANOVA). The results for Experiment 4.2 are summarised in Table 4.8. Key results are reported in the text and remaining results are reported in Appendix 2.

Table 4.8 Main effects and interactions reported in Experiment 4.2. Key: statistical significance status (approaching, yes, no) ✓ depicts results of key theoretical interest.

Result no.	Source	Correct Responses	Incorrect Responses
4.2.1	Mapping rule	No	Yes
4.2.2	Delay	No	Yes
4.2.3✓	X-Y line orientation × Response	No	No
4.2.4✓	Delay × X-Y line orientation × Response	No	No
4.2.5	Delay × Response × Mapping rule	Yes	No

Two-Way Interactions [4.2.3✓]

There was no significant interaction between X-Y line orientation and hand of response, in either RTs [F (1, 18) = 2.547, $p > 0.1$] or mistakes [F (1, 18) = 2.950, $p > 0.1$]. This suggested that the X-Y orientation of a 2D line (collapsed across delays) did not have any associated performance benefits for hand key press responses. See Table 4.9 for associated means.

Table 4.9 Mean RTs (ms), mistakes (%) and standard errors (SE) for result [4.2.3✓]

Ori	Res	ms	SE	%	SE
L	L	429	10	2.8	0.6
L	R	426	10	4.1	0.7
R	L	436	10	4.0	0.7
R	R	423	11	3.4	0.5

Three-Way Interactions [4.2.4✗]

There was no significant interaction between delay, X-Y line orientation and hand of response either in RTs [F (1, 18) = 0.441, $p > 0.5$] or in mistakes [F (1, 18) = 0.479, $p >$ 0.1]. This suggested that the X-Y orientation of a 2D line did not have any associated performance benefits for hand responses at delays of 50 or 100 ms. See Table 4.10 for associated means.

Table 4.10 Mean RTs (ms), mistakes (%) and standard errors (SE) for result [4.2.3✗]

Del (ms)	Ori	Res	ms	SE	%	SE
50	L	L	431	10	2.4	0.8
50	L	R	429	11	3.3	0.5
50	R	L	436	10	3.8	0.6
50	R	R	425	12	2.3	0.4
100	L	L	427	11	3.1	0.8
100	L	R	424	10	4.8	1.3
100	R	L	437	10	4.2	1
100	R	R	421	11	4.5	0.7

4.3.3 Discussion

Following from Experiment 4.1, the narrower aim of this experiment was simply to investigate whether the X-Y orientation of a 2D line would facilitate performance for compatible hand responses (thus testing Visual Attribute Hypothesis 1). Despite having made the colour distinction harder (orange and yellow) and having introduced SOAs of 50 and 100 ms (for the purpose of making participants look at the oriented line for a substantial period of time before responding), the crucial interactions between X-Y line orientation and hand of response [4.2.3✗] and between X-Y line orientation, hand of response and delay [4.2.4✗], did not reach statistical significance. In light of this, it appears that the X-Y orientation of a 2D line is not a visual attribute that affords left-right actions. More specifically, it appears that one potentially action-relevant visual attribute underlying an object's orientation (i.e. its primary axis of elongation in the X-Y plane) is not (by itself at least) a visual attribute that might afford left-right actions (in this instance, hand responses). It was considered possible that the SOA's of 50 and 100 ms might not have provided sufficient processing time to allow the orientation of the line to influence responses. As a final attempt, the last experiment in this series therefore increased the length of SOA's.

4.4 Experiment 4.3

Purely in the interests of thoroughness, this experiment made a final attempt to establish whether the X-Y orientation of a 2D line could by itself influence hand responses (Visual Attribute Hypothesis 1). SOAs of 0, 200 and 800 ms addressed the possibility that a potential influence of X-Y orientation might occur immediately (0 ms)[40], or at considerably later intervals than were tested for in Experiment 4.2 (200, 800 ms). To simplify matters, there was only one mapping condition.

4.4.1 Method

Participants

As Experiment 3.1 (undergraduate volunteers etc.), but fifteen participants took part.

Apparatus

As Experiment 3.1 (darkened room, PC etc.), and the hand response device was used.

Materials

As Experiment 4.2.

Design

The two dependent variables were RTs and mistakes. The three within subjects independent variables were spatial response (left, right), delay (0 ms, 200 ms, 800 ms), and X-Y line orientation (leftwards, rightwards). Thus the experiment was a 2 × 3 × 2 repeated measures design (see Table 4.11). The main experiment consisted of one block of 636 trials. Each variation of coloured line was presented 53 times in each of the three delays (53 presentations × 4 lines × 3 delays = 636 trials). The order of coloured lines was randomised within each delay. As responses were dependent on the line colour, the independent variables of delay and X-Y line orientation were task irrelevant.

[40] Experiment 4.1 (which did not employ delays) had effectively tested the condition of a 0 ms delay. However, as the line colours were different (easier to discriminate), this condition was considered to be worth repeating.

Table 4.11 Experimental design for Experiment 4.3. Key: experimental group (G)

Delay	0 ms	G_1	(n = 15)
	400 ms	G_1	(n = 15)
	800 ms	G_1	(n = 15)
Orientation	Leftwards orientation	G_1	(n = 15)
	Rightwards orientation	G_1	(n = 15)
Response	Left hand response	G_1	(n = 15)
	Right hand response	G_1	(n = 15)

Procedure part a (general procedure)

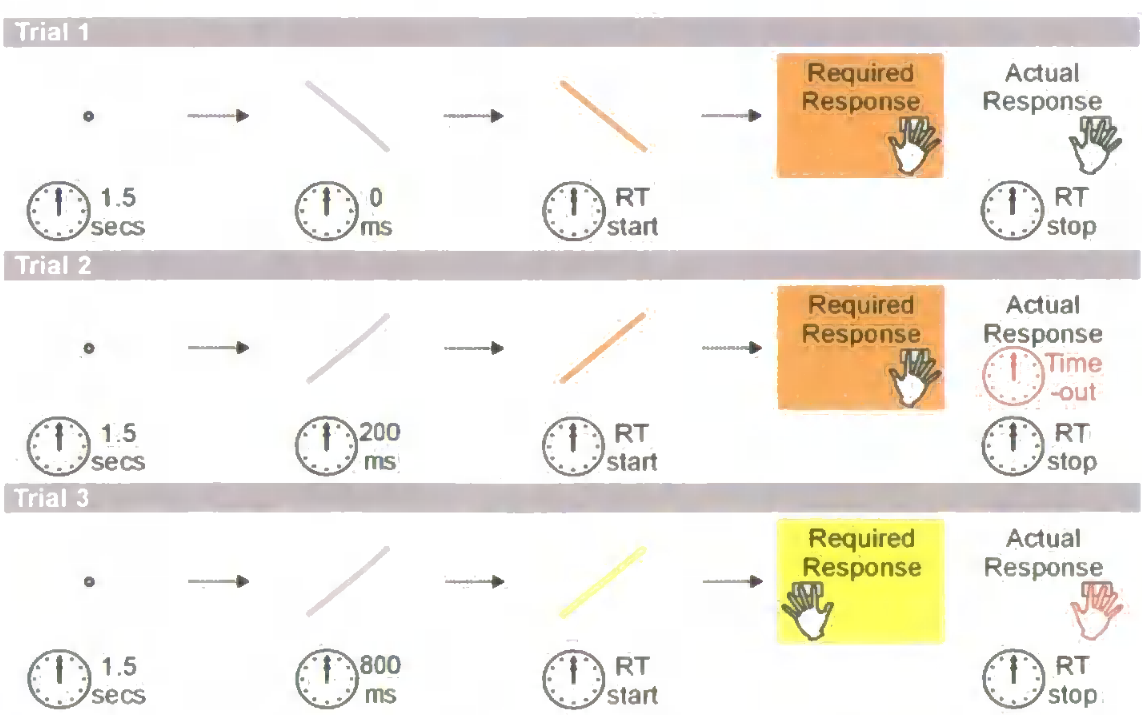
As Experiment 3.1 (consent forms, general instruction of fast and accurate responses etc.).

Procedure part b (trial procedure)

All participants were instructed to make left hand responses to yellow lines, and right hand responses to orange lines. Participants were warned that on some trials a grey line would appear and would change colour after an unspecified period of time. Participants were instructed to respond as soon as the grey line changed colour. After completing the practice session (20 trials), the main experiment began. The trial procedure is outlined in Box 4.3.

Box 4.3 Trial procedure in Experiment 4.3. The clock icon depicts a millisecond timer and the hand icon depicts a hand response. The colour red corresponds to an incorrect response.

The schematic below depicts three typical trials. For each trial, the inter-trial stimulus was shown for 1.5 seconds and was then replaced with the delay stimulus (a grey line) that was shown for 0, 200 or 800 ms. The delay stimulus was then replaced with the target stimulus. A millisecond timer measured the time that the target stimulus remained on the screen. This could be until the participant made a left or right hand response, or until 3 seconds had passed and the trial was given time-out. Following the response (or time-out) the target stimulus was immediately replaced with the inter-trial stimulus for the next trial, thus completing the loop.



4.4.2 Results

Analytical Procedure and Summary Results

Analyses were as described for Experiment 3.1 (correct and incorrect response data sets etc.), but there was only an analysis by participants. Two repeated measures ANOVAs (located in Appendix 1) were performed on the within subjects independent variables of delay, line orientation and hand of response. Participants were entered as a random factor, and the dependent variables were RTs (the first ANOVA) and mistakes (the second ANOVA). The results for Experiment 4.3 are summarised in Table 4.12. Key results are reported in the text and remaining results are reported in Appendix 2.

Table 4.12 Main effects and interactions reported in Experiment 4.3. Key: statistical significance status (approaching, yes, no). ✓ depicts results of key theoretical interest

Result no.	Source	Correct Responses	Incorrect Responses
4.3.1	Delay	Yes	Yes
4.3.2	Response	Approaching	Yes
4.3.3✓	X-Y line orientation × Response	No	No
4.3.4	Delay × Response	Yes	Yes
4.3.5✓	Delay × X-Y line orientation × Response	No	No

Two-Way Interactions [4.3.3✓]

There was no significant interaction between X-Y line orientation and hand of response in either RTs [$F\ (1, 14) = 0.522, p > 0.1$] or mistakes [$F\ (1, 14) = 0.004$, $p > 0.5$]. This again suggested that the X-Y orientation of a 2D line did not have any associated performance benefits for hand key press responses. See Table 4.13 for associated means.

Table 4.13 Mean RTs (ms), mistakes (%) and standard errors (SE) for result [4.3.3✓]

Ori	Res	ms	SE	%	SE
L	L	453	14	1.4	0.5
L	R	441	12	2.4	0.6
R	L	453	12	1.7	0.3
R	R	445	12	2.7	0.6

Three-Way Interactions [4.3.5✓]

There was no significant interaction between delay, X-Y line orientation and hand of response either in RTs [$F\ (2, 28) = 1.112, p > 0.1$] or in mistakes [$F\ (2, 28) = 0.284, p >$

0.5]. This suggested that the X-Y orientation of a 2D line did not have any associated performance benefits for hand responses at delays of 0, 200 or 800 ms. See Table 4.14 for associated means.

Table 4.14 Mean RTs (ms), mistakes (%) and standard errors (SE) for result [4.3.5✗]

Del (ms)	Ori	Res	ms	SE	%	SE
0	L	L	473	15	1.5	0.4
0	L	R	455	14	3.1	0.9
0	R	L	473	14	2.4	0.5
0	R	R	465	16	3.4	1.1
200	L	L	441	13	1.1	0.6
200	L	R	440	10	2.9	1
200	R	L	442	12	1.0	0.3
200	R	R	445	12	3.0	0.7
800	L	L	444	14	1.6	0.6
800	L	R	428	13	1.1	0.4
800	R	L	444	12	1.6	0.7
800	R	R	423	11	1.6	0.5

4.4.3 Discussion

Following directly from Experiment 4.2, this experiment again investigated whether the X-Y orientation of a 2D line would facilitate performance for compatible hand responses. Despite having reused the harder colour distinction (orange and yellow) and having introduced different SOAs of 0, 200 and 800 ms (for the purpose of making participants look at the oriented line for varying periods of time before responding), the crucial interactions between X-Y line orientation and hand of response [4.3.3✗] and between X-Y line orientation, hand of response and delay [4.3.5✗], did not reach statistical significance. In light of this, it again appears that the X-Y orientation of a 2D line did not (by itself at least) afford left-right action.

4.5 General Discussion of Experiments 4.1-4.3

The most important finding from Experiments 4.1-4.3 was the repeated lack of performance-related benefits associated with the X-Y orientation of a 2D line. This lack of an effect remained despite trying different response effectors, colour categories and SOAs.

In conclusion, Experiments 4.1-4.3 *did not* support the hypothesis that the most basic visual attribute underlying an object's orientation (i.e. its primary axis of elongation in the

X-Y plane) might afford left-right actions. Considering this lack of an effect, no legitimate conclusions could be drawn regarding the specificity of left-right actions that might have been afforded (Action Specificity Hypotheses 1-4).

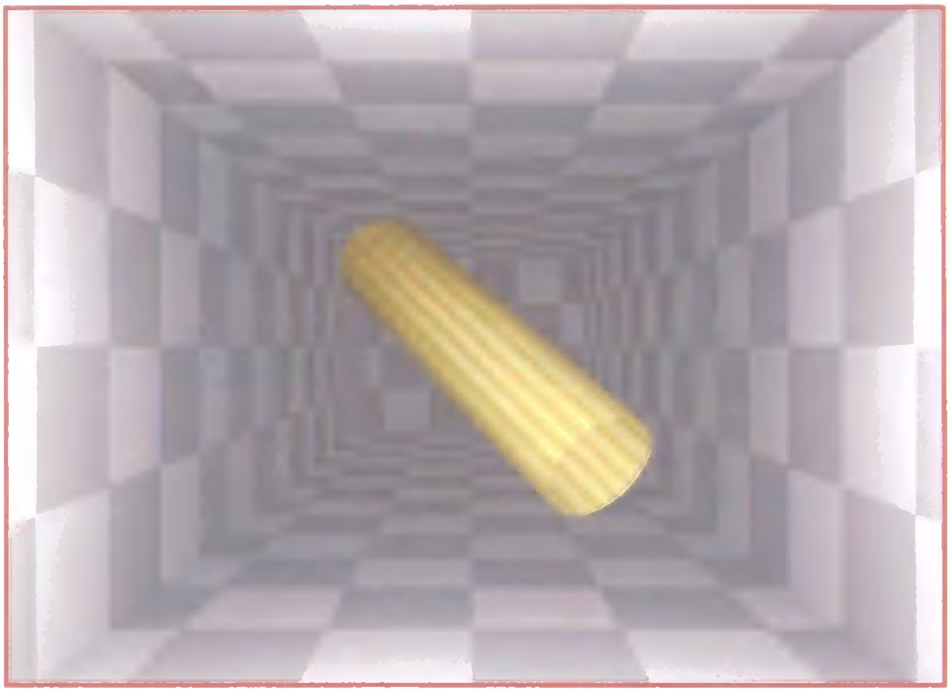
It is possible that the isolated X-Y orientation property of a 2D stimulus might produce performance-related benefits but only under specific conditions that have not been tested for (e.g. at SOA delays other than those used here, for less abstract 2D stimuli, or for 2D stimuli that are given a behavioural significance). Any number of SOA manipulations might be investigated. However, it was considered unlikely that such an approach would be fruitful, bearing in mind the results obtained here. Alternatively, a 2D stimulus oriented in the X-Y plane might be given some sort of meaning or visual saliency (e.g. a 2D depiction of a real 3D object). For example, an arrowhead or shape attached to one end of a diagonal line might produce compatibility effects. Indeed, such compatibility effects might be expected. An arrow pointing left, for example, would presumably promote left responses. Similarly, a blob attached to the leftmost end of a line might promote left responses. Furthermore, the orientation of a 2D stimulus might be endowed with a behavioural significance that must be understood in order to perform the task (e.g. one might have to mentally rotate a 2D line clockwise or anticlockwise in order to match a target). Such manipulations however, would not say much about a *specific visual attribute* of an object's orientation (such as orientation in the X-Y plane), but rather would inform about the influence of the added visual or behavioural component. For this reason, such a line of inquiry was not pursued [41].

Nevertheless, there are other possible reasons why no compatibility effects were found with respect to the visual attribute of X-Y orientation. It may be that the isolated X-Y orientation property of a stimulus simply does not evoke performance-related benefits (i.e.

[41] Indeed, as has been previously discussed, the 'attention-directing hypothesis' provided by Anderson et al (2002) tested these very intuitions. Not surprisingly, the data suggested that a point of visual and/or behavioural salience on a 2D object or shape (such as a large blob, or a graspable area) promoted compatible responses.

does not afford left-right actions). On the other hand, it may be that a stimulus must be 3D in order for X-Y orientation to exert an influence on responses. Alternatively, orientation-action compatibility effects may relate to orientation in another dimension altogether, such as the X-Z plane (i.e. the depth plane). In order to test these possibilities, the use of 3D oriented objects would be required. Ideally, orientation within the three dimensions should remain free from additional object properties (as was the case in 2D, where the line had no geometrical features other than its axis of elongation). One possible extension of a 2D line in this vein would be a 3D cylinder. Using a computer-generated 3D cylinder that is oriented in 3D space would have the advantage of simultaneously testing for the influence on spatial responses of three interacting planes of object orientation (X-Y plane, Y-Z plane and X-Z plane). These planes could be separated in the statistical analyses, thus allowing for an investigation of the relative influence that orientation in each plane had on response performance. Chapter 5 adopted this approach.

5. Three-dimensional (3D) object orientation



Contents

5.1 Experimental Hypotheses and Overview

Objective 3: To test for orientation-action compatibility effects associated with computer-generated three-dimensional cylinders that are oriented in three-dimensional space, thus exploring the possibility that a specific visual attribute (i.e. the angle of an object's primary axis within a particular three-dimensional plane) might afford left-right actions. Using these stimuli, different left-right response types are used in order to test whether any compatibility effects are specific to hands, or viable for a range of actions.

This chapter follows on from Chapter 4 by addressing the issues of visual attribute specificity and action specificity with relation to a 3D object. To reiterate, the orientation-action compatibility effects of Tucker and Ellis (1998) did not distinguish between a number of possibilities. Two of these possibilities were as follows:

Firstly, if these effects reflected the automatic potentiation of left-right actions associated with purely visual attributes of an object (possibly through activating a 'default representational setting' that is abstracted from viewing an oriented object); then one must ask what these visual attributes are. It was concluded from Experiments 4.1-4.3 that orientation in the X-Y plane did not, by itself at least, present a visual attribute that evoked any affordance for left-right actions.

Secondly, there is the possibility that the motor components of potential visual attribute-related affordances are abstract or primitive enough to influence a range of compatible responses, particularly if these responses are 'set up' in the first place by the physical context of the task. Experiment 3.1 provided some evidence supporting this notion, by establishing orientation-compatibility effects using foot responses.

The three experiments reported below re-addressed these two possibilities using 3D graphically rendered cylinders. In addressing the specificity of left-right actions afforded, the four Action Specificity Hypotheses generated in Chapter 3 remained under investigation (1- a specific action property is afforded that is exclusive to one action; 2- a primitive action property is afforded that is common to many actions; 3- a specific action property is maximally afforded but other action properties are to a lesser extent activated;

4- a range of actions can be afforded by virtue of being physically 'set up' by task parameters).

Although the cylinder stimuli used are described in detail in the method section of Experiment 5.1, it may be useful at this stage to see an example global orientation of a 3D cylinder, which can be described in terms of the three dimensional planes (see Figure 5.1).

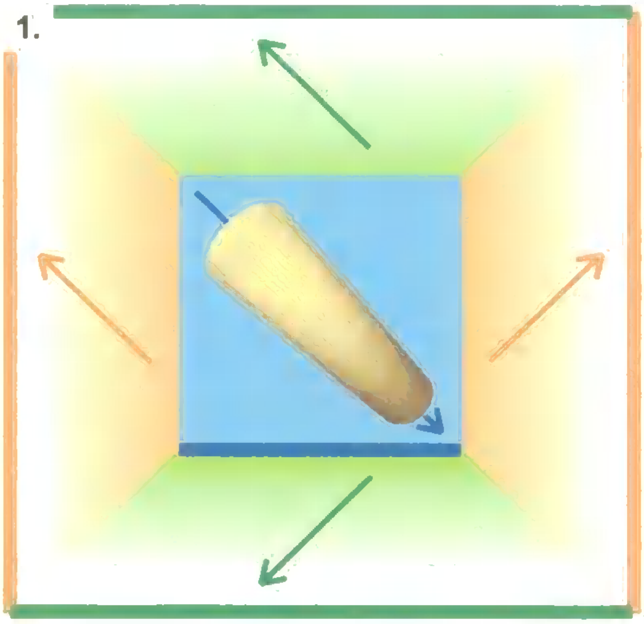


Figure 5.1 An image of a 3D cylinder that is oriented in 3D space. The blue wall represents the X-Y plane (i.e. the frontal or picture plane), the orange walls represent the Y-Z plane (i.e. the saggital plane), and the green walls represent the X-Z plane (i.e. the horizontal or depth plane). The thick coloured lines represent an arbitrary reference point in each plane. These reference points allow the orientation lines that are projected on each planar wall to have an arrowhead (which always points towards a reference point). Using these arrows, it can be seen that the example cylinder is oriented rightwards in the X-Y plane, upwards in the Y-Z plane and leftwards in the X-Z plane.

In addressing the specificity of visual attributes that might afford left-right actions, the following three hypotheses were under investigation:

Visual Attribute Hypothesis 1: The most basic property of an object's orientation (its primary axis of elongation in the X-Y plane) is a specific visual attribute that affords components of left-right actions. Facilitation might occur for left or right responses that are compatible with this X-Y orientation.

Although evidence from 2D stimuli did not support this first hypothesis (see Experiments 4.1-4.3), it may be the case that the X-Y orientation of a 3D object affords components of left-right actions. Finding that the X-Y orientation of a 3D object did not facilitate compatible responses might suggest that as a basic visual attribute, orientation in the X-Y plane simply does not afford components of left-right actions.

Visual Attribute Hypothesis 2: The 'up-down' dimension of an object's orientation (its primary axis of elongation in the Y-Z plane) is not a specific visual attribute that affords components of left-right actions, since it is not a 'left-right' dimension. Consequently facilitation of a particular spatial response should not occur with relation to Y-Z orientation.

Visual Attribute Hypothesis 3: Another property of an object's orientation (its primary axis of elongation in the X-Z plane) is a specific visual attribute that affords components of left-right actions. Facilitation might occur for responses that are compatible with this X-Z orientation.

Alternatively, as this third hypothesis suggests, it is possible that another aspect of an object's orientation affords components of left-right actions, such as the visual cue of orientation in the X-Z plane. Indeed, when orientation-action compatibility effects have been observed with photographs of real objects (e.g. Experiment 3.1; Symes, 1999; Tucker & Ellis, 1998) the objects were oriented in the X-Z plane.

In testing these three Visual Attribute Hypotheses, Experiments 5.1-5.3 investigated spatial (left or right) responses that were made to the surface pattern of an oriented 3D cylinder. In responding to the cylinder's surface pattern, the orientation of the cylinder was task irrelevant. Consequently it was assumed that any orientation-action compatibility effects obtained would reflect a goal-independent automatic activation of afforded motor properties. There were four variations of this cylinder's *global* orientation. Crucially, each global orientation was derived from the interaction of local orientations within each dimensional plane. The orientation of a cylinder within each plane could be isolated statistically, thus providing an opportunity to see whether any orientation-compatibility effects were specific to the X-Y, Y-Z or X-Z planes. The results consistently provided support for Visual Attribute Hypothesis 3. Thus when the closest end of a cylinder in the X-Z plane pointed leftwards, performance was best for left responses (and vice versa for rightwards pointing cylinders). No such benefits were associated with the X-Y plane (thus refuting Visual Attribute Hypothesis 1); a finding that suggested (in accordance with Experiments 4.1-4.3) that orientation in the X-Y plane did not afford components of left-right actions. Furthermore, support was provided for Visual Attribute Hypothesis 2, such that orientation in the Y-Z plane did not influence left-right responses.

In testing Action Specificity Hypotheses 1-4, Experiments 5.1-5.3 investigated different left-right responses that were made to the same stimuli. Three different response types were used; 1) left and right-hand key press responses that were considered analogous to the initiation of a reaching movement towards the cylinder; 2) Left and right-hand power grip responses that were considered analogous to a grasp appropriate for picking up the cylinder; 3) Left and right foot responses that bore no obvious action association with the cylinder. The pattern of results was essentially the same for all three response types (promoting Action Specificity Hypothesis 2, whereby a primitive action property is afforded that is common to many actions). However, there was a hint that X-Z orientation-action compatibility effects for power grip responses were larger than those for foot responses; a finding that provided some support for Action Specificity Hypothesis 3 (which proposed that a specific action property is maximally afforded but other action properties are to a lesser extent activated). In addition, the fact that a range of different response types produced X-Z orientation compatibility effects is consistent with Action Specificity Hypothesis 4, which proposed that a range of actions can be afforded by virtue of being physically 'set up' by task parameters.

It was concluded that orientation within the X-Z plane is an identifiable visual attribute that that can evoke an affordance for components of left-right actions. Furthermore, in keeping with the findings of Experiment 3.1, the idea of an amodal action-oriented representation was supported. The motor component of this 'default' representation was presumably abstract or primitive enough to influence various kinds of response.

5.2 Experiment 5.1

One might expect that the dimensionality of an object would influence the kind of actions that one makes towards it. 2D shapes do not intuitively afford a wide range of actions, and from this general perspective it is not too surprising that X-Y orientation did not influence left-right responses in the previous chapter. 3D objects on the other hand, have a quality about them (a three-dimensional quality) that opens up the possibilities for action. Furthermore our history of interactions with the world is predominantly associated with 3D objects and surfaces.

Research on the relationship between action and perceived object dimensionality supports the intuition that objects presented as 2D or 3D might affect actions differentially. Castiello, Bonfiglioli and Bennett (1996) manipulated the *perceived* dimensionality of an apple that participants were required to reach towards and pick up. Under normal lighting conditions the apple was perceived as 3D, whereas under special lighting conditions that made the apple appear as a dark silhouette, the same apple was perceived as 2D. When the apple was perceived as 2D, it was picked up using a large precision grip made between forefinger and thumb (as if the apple that was being picked up were a disc). When the apple was perceived as 3D, it was picked up using a power grip made with a whole hand prehension (where all digits and the palm contacted its surface). On some trials the perceived object dimensionality was perturbed, such that the object was initially perceived as 2D and then changed to 3D just as the reach movement was initiated. On these trials participants demonstrated a transition from an initial precision grip to a power grip during the reach (transport component), resulting in the apple being picked up (manipulation component) with a whole hand prehension. Castiello, Bonfiglioli and Bennett (1998) replicated these results and additionally showed the opposite transition of grip type when perturbations went from 3D to 2D (although only in the manipulation component and not the transport component of the grip).

These results are particularly interesting because the to-be-grasped object was always the same, namely a real 3D apple. Participants knew this, yet still their grasp patterns were differentially influenced by perceived visual dimensionality[42]. It is also interesting that in the case of perturbed trials, an initial grip type could be overridden or transformed by a more dimension-appropriate grip. These results support the idea of 'representational defaults' discussed in Chapter 3. These defaults (which may be dimension-specific) are directly triggered by the *visual attributes* of an object (as evidenced by the influence on grip type of perceived dimensionality); and furthermore, they can be transformed, elaborated or rejected as required (as evidenced by the grip transitions during the perturbation trials). Interestingly, however, the semantic knowledge of how apples are usually picked up, apparently played little or no part in determining what grip-type was used. According to the arguments developed in Chapters 2 and 3, such practical knowledge might be expected to have an influence. Nevertheless, it may be the case that in this instance the 'default' was sufficiently robust to resist intervention (although as footnote 42 below shows, a limited number of trials did suggest otherwise). Furthermore, had the task required a different outcome, such as a requirement to reach and grasp the apple and then throw it towards a target; it may well be that within this behavioural context the demands of the task would indeed override the influence that 2D visual attributes had on grip type.

Castiello et al. (1996, 1998) argued that these results implicated visual mechanisms for interpreting an object's dimensions. These mechanisms directly influence motor selection pathways without necessarily accessing a 3D central nervous system representation of the object. Under a single-level representation view (such as a stored object model from which associated actions could be derived), a whole hand prehension might be expected *regardless* of the perceived dimensionality.

[42] Castiello et al. (1998) interpreted a very low incidence of a) trials where whole hand prehension was used for the 2D apple, and b) 'hybrid grasps' that were somewhere between precision and power; as reflecting a default level of inter-channel cross-talk, or at least a suggestion that a 3D representational level is not *entirely* ignored.

Instead, Castiello et al. (1998) argued for the use of separate (but interacting) levels of representation (or 'different channels of visual interpretation'), along the lines of Marr's (1982) three stages of computation (i.e. the primal sketch, 2½ D sketch and 3D model). They also alluded to the 'what' and 'how' visual systems, suggesting that their results implicated the 'how' pathway, where dimension was processed using early access to spatial pathways and to presemantic components or neural mechanisms that bypass elements of the 'what' pathway. Thus in bypassing the 'what' processing of an apple, the online 'how' processing of a perceived 2D silhouette resulted in a precision grip (appropriate for picking up a disc say, but inappropriate for picking up an apple).

Bearing in mind that the (perceived) dimensionality of an object can differentially affect action, and that this seems to be a purely visual attribute based phenomenon; it is possible that while the visual cue of orientation in 2D space may not influence responses (e.g. orientation in the X-Y plane as used in Chapter 4), a visual cue of orientation in 3D space might. One would not necessarily expect orientation in Y-Z plane to influence spatial left-right responses, as orientation within this plane can be characterised as an upwards-downwards spatial relationship (see Visual Attribute Hypothesis 2). However, in looking for a visual attribute of an object's orientation that evokes an affordance for left-right actions, orientation in the X-Z plane (i.e. the depth plane) would seem to be a likely candidate. Indeed, the photographs of real-world objects used by Tucker and Ellis (1998) (and Experiment 3.1 above), were all oriented in the X-Z plane, and hence had a clear left-right dimension. However, as has already been argued, these objects all had functional connotations associated with their handles, and as such one cannot be sure that the orientation-action compatibility effects found reflected the influence of orientation in the X-Z plane, or the influence of visually or functionally salient features (as was argued by Anderson et al., 2002). Thus Experiment 5.1 tested the influence that a functionally neutral cylinder (that was systematically oriented in the X-Y, Y-Z and X-Z planes) had on left-right key press responses.

5.2.1 Method

Participants

As described for Experiment 3.1 (undergraduate volunteers etc.), but 20 participants took part.

Apparatus

As described for Experiment 3.1 (small darkened room, PC etc.), but a new response device was used. *The response device:* A wooden board with two inlaid micro-switches fixed approximately 40cm apart. Hinged Perspex flaps covered the micro-switches. This device could be used as a hand response device (when located on the table directly in front of the monitor), and as a foot response device (when located on the floor directly under the monitor). In this experiment (5.1) it was used as a hand response device.

Materials

The surrounding screen background was a light grey colour at all times. The inter-trial stimulus was a grey chequered room designed to give the impression of depth. The target stimulus set was created from a computer generated hollow cylinder that was set, floating, in the centre of the chequered room (see Figure 5.2).

The cylinder was manipulated in two surface patterns and four global orientations, resulting in a stimulus set of eight cylinders. One surface pattern had the appearance of a 'wobbly' wood pattern, and the other pattern had the appearance of a 'straight' wood pattern. Because the cylinders were manipulated in 3D space, their global orientation could be described in terms of the three dimensional planes (see Figure 5.3).

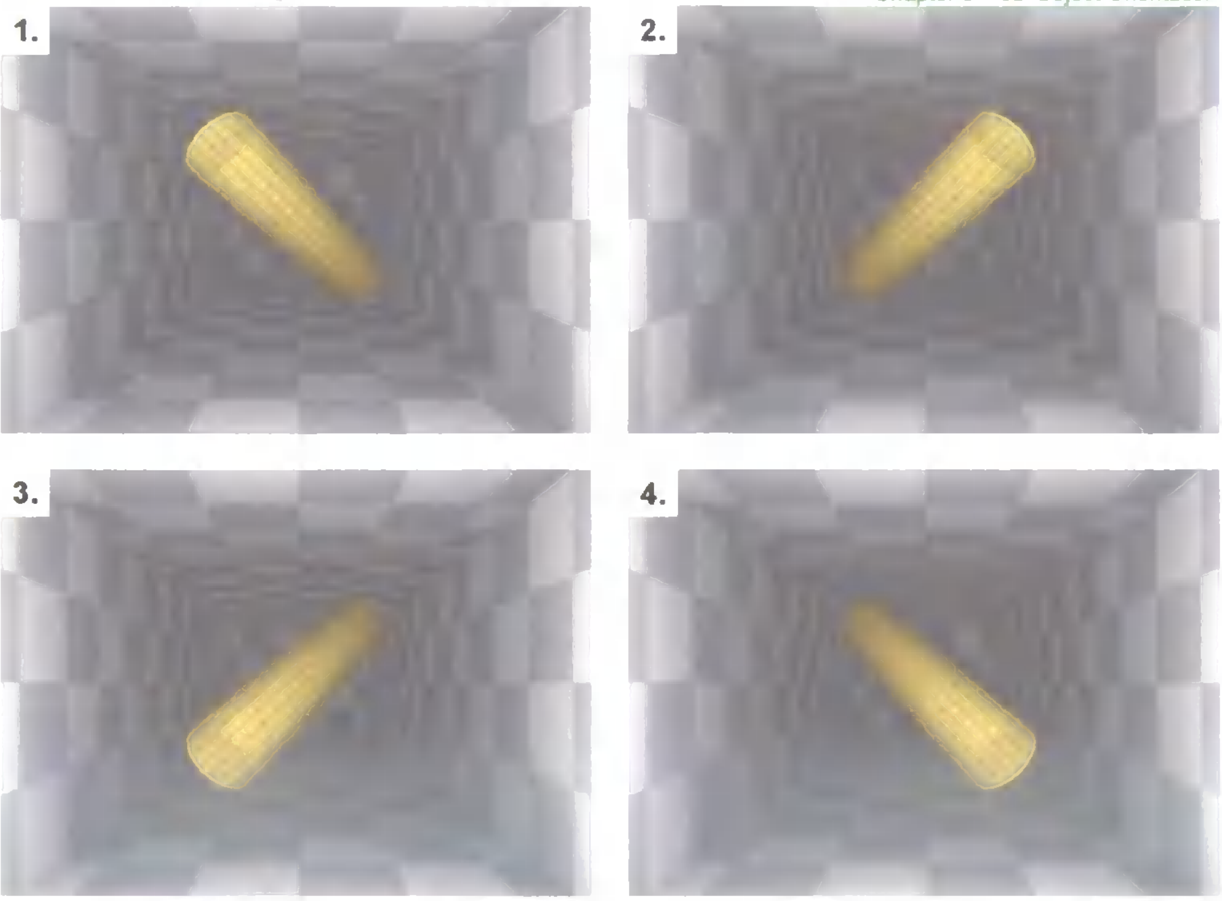


Figure 5.2 The four global orientations of cylinders used in Experiment 5.1. Only cylinders with a straight surface pattern are shown[43].

[43] Design considerations relating to 3D objects: It is a fact that when one looks at an object in normal lighting and viewing conditions, one can see its leading edge, but of course, one cannot see the whole rear end of the object (i.e. behind it). Furthermore, this leading edge is larger and brighter than the rear end of the object. In addition, when an object is oriented (even if it is *directly* in front of a viewer in terms of its real-world physical coordinates), the end that is closest to the viewer will appear enlarged and thus will spatially protract, whereas the farthest end will appear to have shrunk, and thus will spatially retract.

Inevitably then, a design decision had to be made regarding the theoretical implications of these features with respect to 'attention-directing' accounts of S-R-C effects. Should one try and control all of these naturally occurring features of an object that might be visually salient and hence attention-grabbing? For instance, one might artificially manipulate lighting conditions such that each end of the cylinder had the same illumination values. One might also artificially shrink the radius of the leading edge of the cylinder such that each end had the same *visual* radius. One might also superimpose a disc on the farthest end of the cylinder (much like an 'impossible figure' illusion) such that each end of the cylinder had a visible leading edge. One might also artificially shift the cylinder slightly up or down and left or right to remove signs of spatial protraction and retraction. Just what the end result would look like is unclear, but it would certainly not look like a cylinder oriented in 3D space, for it would have lost all of the qualities that made it a 3D object.

Alternatively one could commit to an ecologically valid stimulus, and accept that these visually salient features are a basic fact about real 3D objects in 3D space. All things considered, it was decided to design and create the most ecologically realistic cylinder possible (within reason). Issues of attention, while theoretically problematic for the current investigations, were instead addressed separately in the next chapter. So, although the oriented cylinder used in this and later experiments was a perfectly symmetrical object that was exactly centred (left-right and top-bottom) using simulated real-world coordinate and lighting systems, it nevertheless had a slightly protracting visually salient circular area at its leading edge.

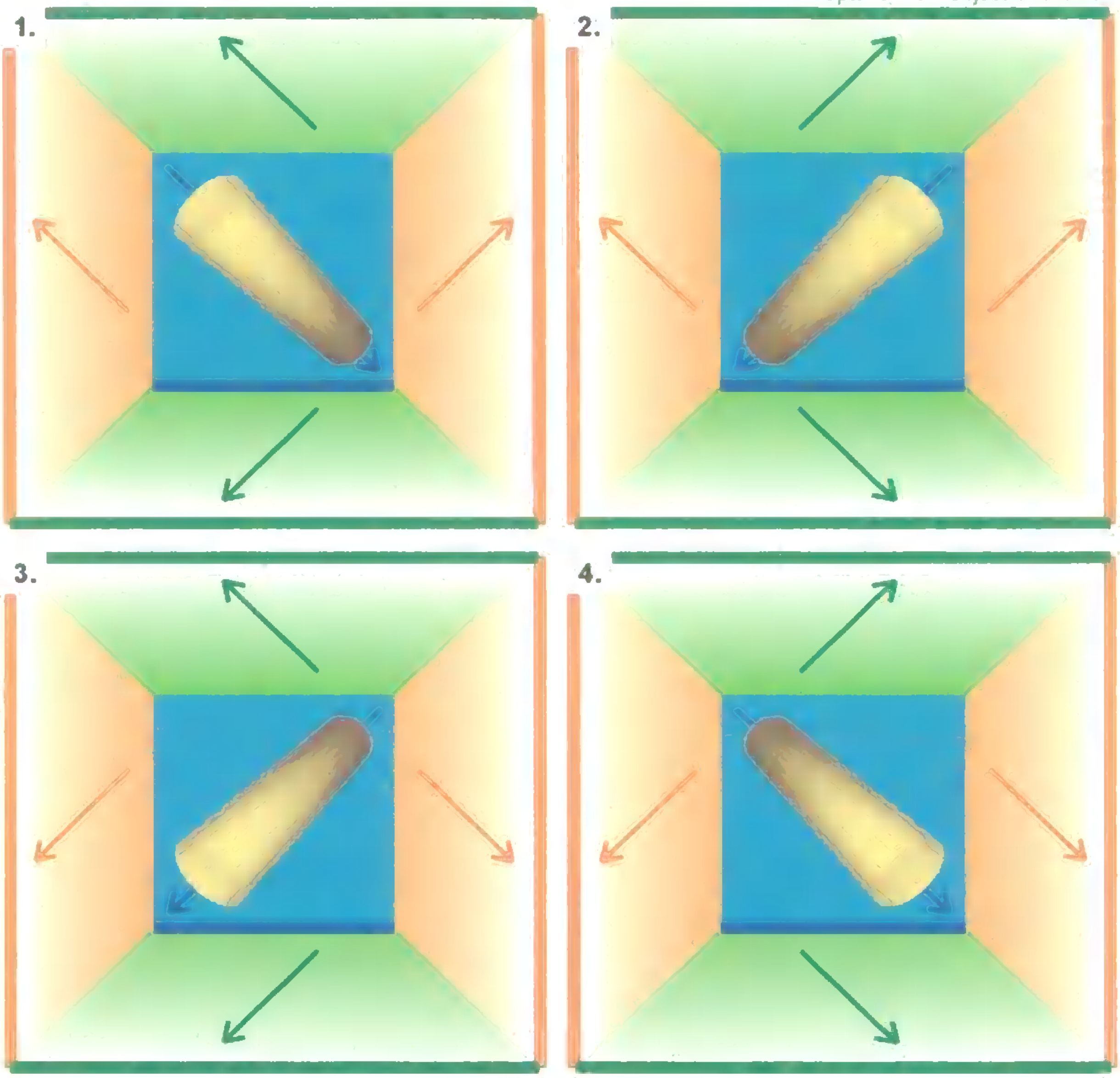
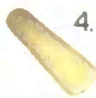


Figure 5.3 The four global orientations of cylinders used in Experiment 5.1, as shown within the context of the X-Y plane (blue), the Y-Z plane (orange) and the X-Z plane (green). The thick coloured lines represent an arbitrary reference point in each plane. These reference points allow the orientation lines that are projected on each planar wall to have an arrowhead (which always points towards a reference point). The direction that an arrow points thus defines the orientation of the cylinder within a particular plane. These definitions are formalised in Table 5.1.

Based on the graphical description given in Fig. 5.2, each global orientation was defined in terms of its orientation within each of the three planes (see Table 5.1). The angle of the cylinder was always 45° or 135° within each plane. Details of how these planes are reported in the data are provided later (see section 5.2.2).

Table 5.1 A definition of each globally oriented cylinder in terms of its dimension-specific orientations. The icons are used later when explaining the analysis of stimulus dimensions.

Global Cylinder Orientation	Dimension-Specific Orientation	Dimension-Specific Icon
 1.	X-Y (Rightwards); Y-Z (Upwards); X-Z (Leftwards)	
2. 	X-Y (Leftwards); Y-Z (Upwards); X-Z (Rightwards)	
3. 	X-Y (Leftwards); Y-Z (Downwards); X-Z (Leftwards)	
 4.	X-Y (Rightwards); Y-Z (Downwards); X-Z (Rightwards)	

Design

The two dependent variables were RTs and mistakes. The within subjects independent variables were hand of response (left, right), and a choice of two of the following[44]: X-Y cylinder orientation (leftwards, rightwards), Y-Z cylinder orientation (upwards, downwards) or X-Z cylinder orientation (leftwards, rightwards). The between subjects independent variable was mapping rule. Thus the experiment was based on a 2 × 2 × 2 × 2 repeated measures design, as illustrated in Table 5.2.

Table 5.2 Experimental design for Experiment 5.1. Key: mapping rule (MR), condition 1 (C1), condition 2 (C2), experimental group (G)

		MR	
		C1	C2
Hand of Response	Left	G_1 (n = 10)	G_2 (n = 10)
	Right	G_1 (n = 10)	G_2 (n = 10)
X-Y cylinder orientation	Leftwards	G_1 (n = 10)	G_2 (n = 10)
	Rightwards	G_1 (n = 10)	G_2 (n = 10)
Y-Z cylinder orientation	Upwards	G_1 (n = 10)	G_2 (n = 10)
	Downwards	G_1 (n = 10)	G_2 (n = 10)
X-Z cylinder orientation	Leftwards	G_1 (n = 10)	G_2 (n = 10)
	Rightwards	G_1 (n = 10)	G_2 (n = 10)

[44] It should be noted that the cylinder orientation in a particular plane (e.g. X-Z plane) is *necessarily* specified by the interaction of cylinder orientations in the other two planes (e.g. X-Y × Y-Z planes). For example, a cylinder oriented leftwards in the X-Y plane and downwards in the Y-Z plane, *must*, as a consequence, be oriented leftwards in the X-Z plane. Therefore only two planes need to be entered as variables in the design. However, in order to have access to a range of mean RT and mean mistake data, multiple analyses were performed using all combinations of two stimulus variable designs.

In mapping rule: condition 1 (MR: C1) [n = 10], left hand responses were made to cylinders with a wobbly surface pattern and right hand responses were made to cylinders with a straight surface pattern. The 'hand of response-cylinder pattern' pairing was reversed in mapping rule: condition 2 (MR: C2) [n = 10]. A practice session consisted of 20 overt practice trials, and 40 covert practice trials, which served to pressurise participants to try harder in the practice so as to reach a consistent performance for the main experiment. The main experiment consisted of 400 trials, divided into 20 blocks of 20 trials. Both cylinder patterns were shown 50 times for each of the four global cylinder orientations (thus 50 presentations × 2 patterns × 4 global cylinder orientations = 400 trials). The order of cylinder pattern and global cylinder orientation was randomised in one block of 400. As responses were dependent on the pattern of the cylinder, the independent variables of cylinder orientation (X-Y, Y-Z and X-Z) were task irrelevant.

Procedure part a (general procedure)

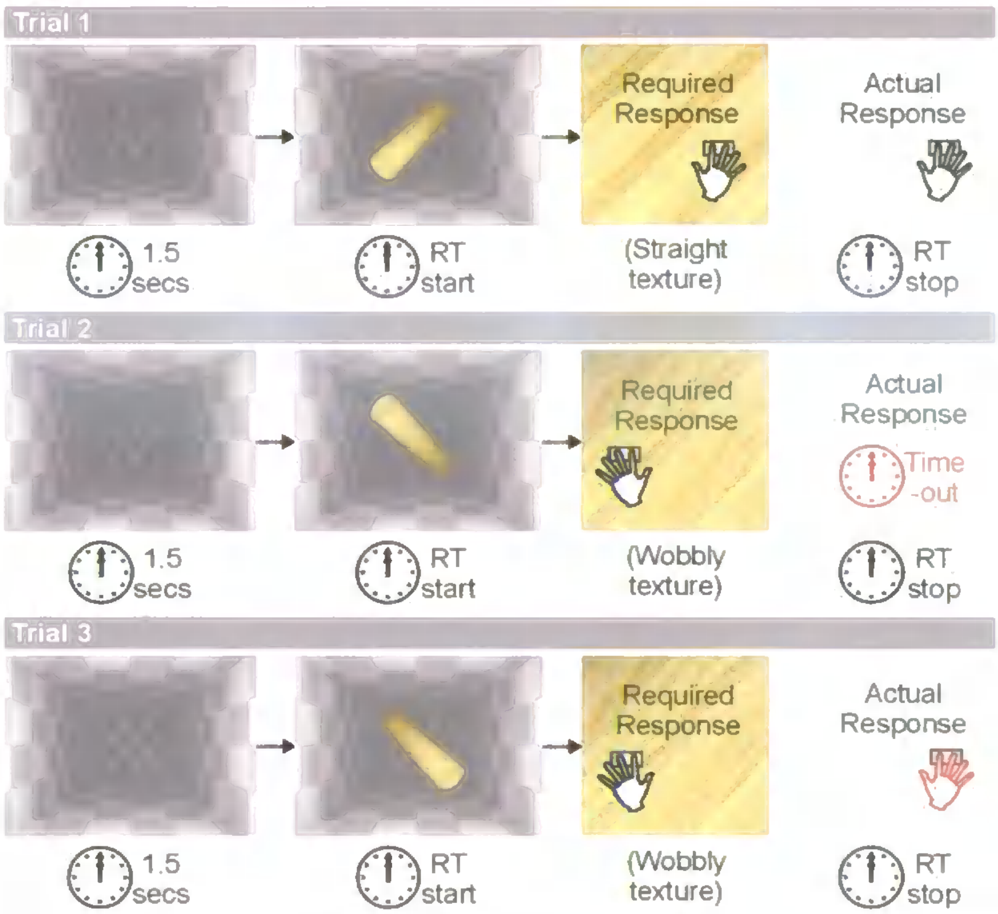
As described for Experiment 3.1 (consent forms, general instruction of fast and accurate responses etc.).

Procedure part b (trial procedure)

Participants were pseudo-randomly allocated to an experimental group (Group 1- MR: C1, Group 2- MR: C2). According to their group allocation, they were instructed which hand to respond with for the two cylinder patterns. After completing the practice session, the main experiment began. The trial procedure is outlined in Box 5.1.

Box 5.1 Trial procedure for Experiment 5.1. The clock icon depicts a millisecond timer, and the hand icon depicts a hand key press. The colour red corresponds to an incorrect response.

The schematic below depicts three typical trials for a participant assigned to MR: C1 (left responses for wobbly cylinder pattern, right responses for straight cylinder pattern). For each trial, the inter-trial stimulus was shown for 1.5 seconds and was then replaced with the target stimulus. A millisecond timer measured the time that the target stimulus remained on the screen. This could be until the participant made a left or right response, or until three seconds had passed and the trial was given time-out. Following the response (or time-out), the target stimulus was immediately replaced with the inter-trial stimulus for a new trial, thus completing the loop.



Procedure part c (feedback routine)

The experiment was split into 20 blocks of 20 trials. After each block of 20 trials (including the practice block), participants were shown a graphical output of their performance in two bar charts. These charts were presented next to each other on the screen, and after examination of their progress, the spacebar served to initiate the next block of trials. Participants were shown how to interpret the two charts, and were instructed to use the charts as a guide to keeping their performance as consistent as possible.

Experimental progress chart: This chart gave participants an opportunity to monitor their overall experimental progress. The chart updated a block at a time (i.e. new bars were added upon completion of each block), with blue bars representing correct responses (corresponding to the principal Y-axis) and red bars representing mistakes (corresponding to the secondary Y-axis). Mean RTs in milliseconds (for a given block of 20 trials) were shown along the principal Y-axis, a count of mistakes was shown along the secondary Y-axis, and block numbers along the X-axis.

Previous block performance chart: This chart gave participants an opportunity to monitor their actual performance for the just-completed block. For each of the 20 trials there was either a blue bar (representing a correct response) or a red bar (representing a mistake). Actual RTs in milliseconds (for a given trial) were shown along the Y-axis, and trial numbers along the X-axis.

5.2.2 Notes to explain the analyses

Sources of data

The following series of Figures explain exactly what the data corresponds to, when orientations within a particular plane are referred to in the results (for the X-Y plane, see Figure 5.4; for the Y-Z plane, see Figure 5.5; for the X-Z plane, see Figure 5.6).

Example data for the X-Y plane: Suppose that a main effect was found for X-Y orientation in RTs. On average, cylinders oriented rightwards in the X-Y plane were responded to 25 ms faster than cylinders oriented leftwards. The data that revealed this main effect would have come from the following information: the average RTs for responses made to the two cylinders in Fig. 5.4A (e.g. 520 ms), compared to the average RTs for responses made to the two cylinders in Fig. 5.4B (e.g. 495 ms). The data comes from a combination of these specific cylinders because there are only two cylinders that have a leftwards X-Y orientation (2 & 3), and there are only two cylinders that have a rightwards X-Y orientation (1 & 4). For example, in considering Fig. 5.4A (cylinders 2 & 3), these two cylinders share no other features in any other planes (e.g. cylinder 2: Y-Z = upwards, X-Z = rightwards; cylinder 3: Y-Z = downwards, X-Z = leftwards); thus the *only* feature that they have in common is a leftwards orientation in the X-Y plane. Therefore, to reiterate, in order to examine information about orientation in the X-Y plane, mean RTs must be collapsed across the data obtained for cylinders 2 & 3 (leftwards) and cylinders 1 & 4 (rightwards).

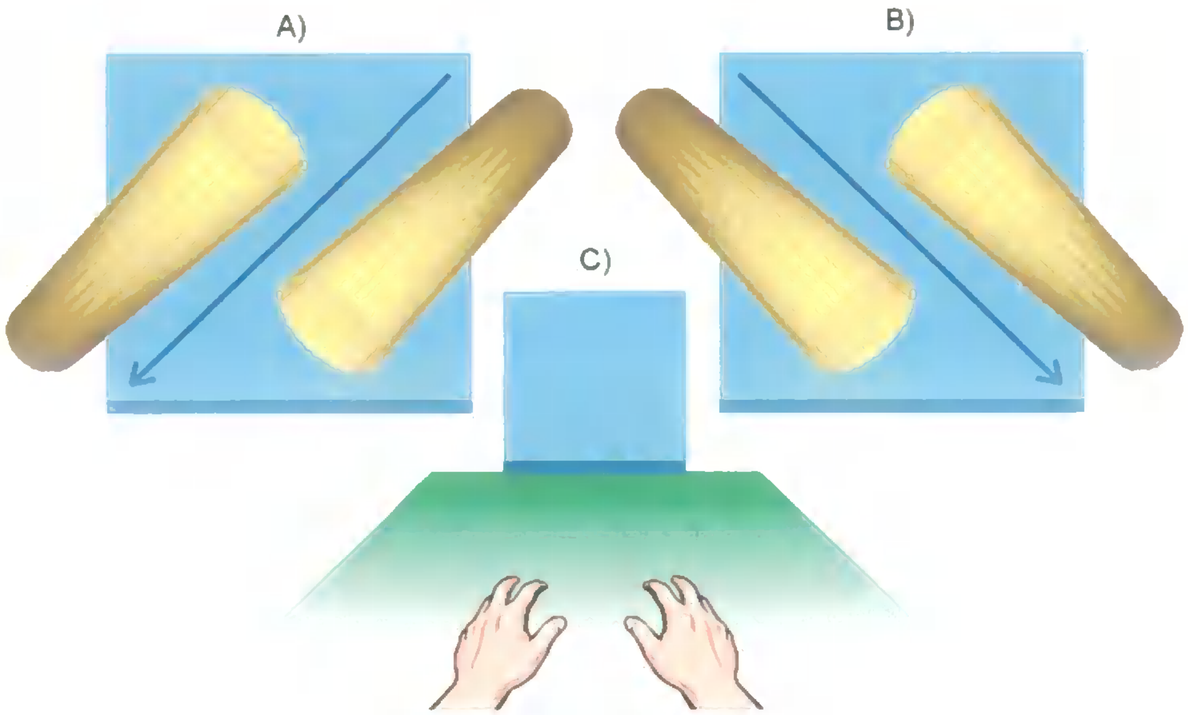


Figure 5.4 The X-Y plane. A) Global cylinder orientations 2 & 3 are shown (as numbered in Figs. 5.1 & 5.2). These are the only two cylinders that share as their common feature a leftwards orientation in the X-Y plane. B) Global cylinder orientations 1 & 4 are shown (as numbered in Figs. 5.1 & 5.2). These are the only two cylinders that share as their common feature a rightwards orientation in the X-Y plane. C) This illustration depicts the X-Y plane to help visualise the dimension under discussion. Note the arbitrary reference point (a thick blue line) that allows the definition of leftwards and rightwards orientations through the use of arrowheads that point towards it.

Exactly the same logic applies to the Y-Z plane (see Fig. 5.5), where mean RTs must be collapsed across the data obtained for cylinders 1 & 2 (upwards) and cylinders 3 & 4 (downwards); and the X-Z plane (see Fig. 5.6), where mean RTs must be collapsed across the data obtained for cylinders 1 & 3 (leftwards) and cylinders 2 & 4 (rightwards).

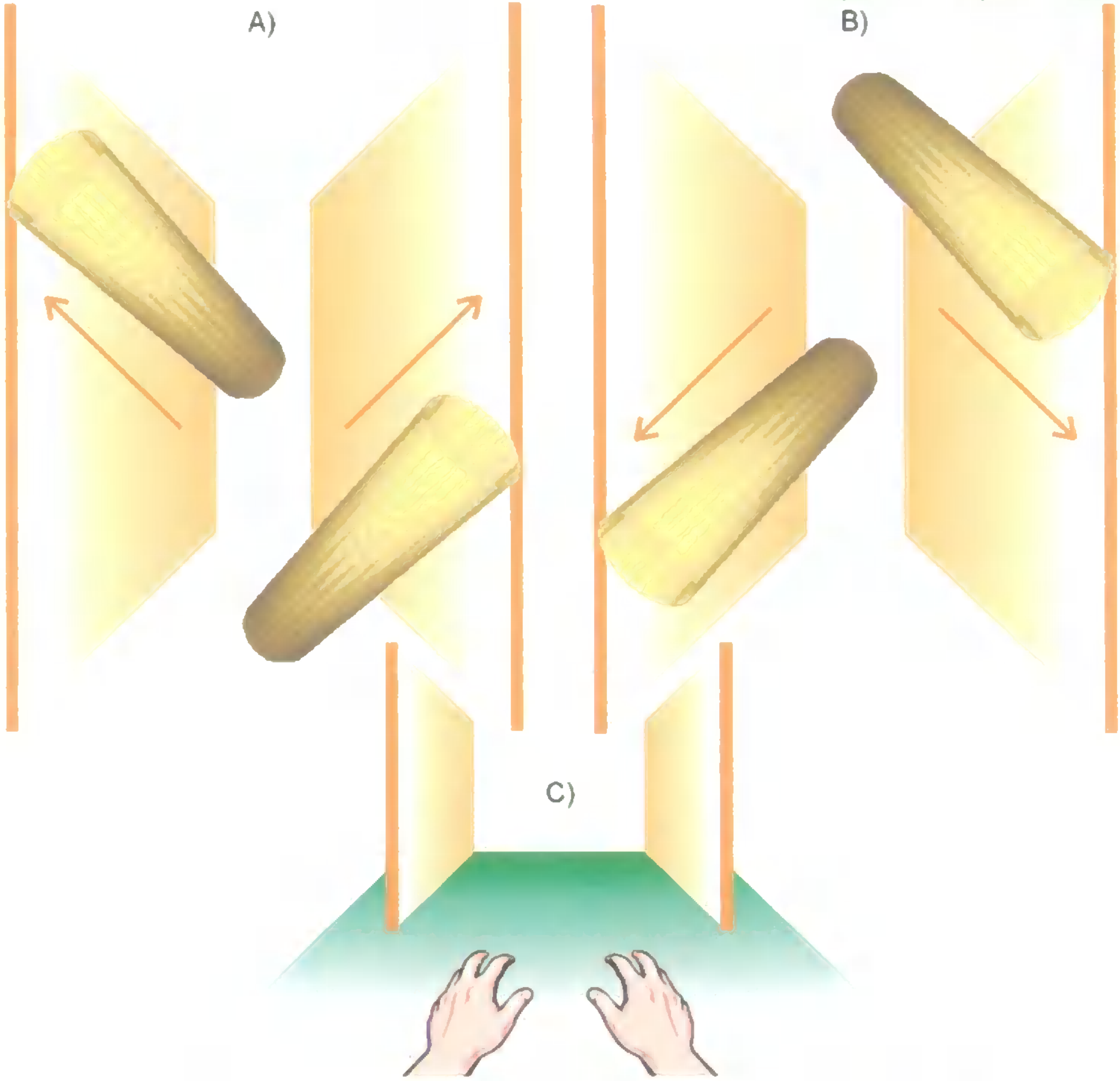


Figure 5.5 The Y-Z plane. A) Global cylinder orientations 1 & 2 are shown (as numbered in Figs. 5.1 & 5.2). These are the only two cylinders that share as their common feature an upward orientation in the Y-Z plane. B) Global cylinder orientations 3 & 4 are shown (as numbered in Figs. 5.1 & 5.2). These are the only two cylinders that share as their common feature a downward orientation in the Y-Z plane. C) This illustration depicts the Y-Z plane to help visualise the dimension under discussion. Note the arbitrary reference point (a thick orange line) that allows the definition of upward and downward orientations through the use of arrowheads that point towards it.

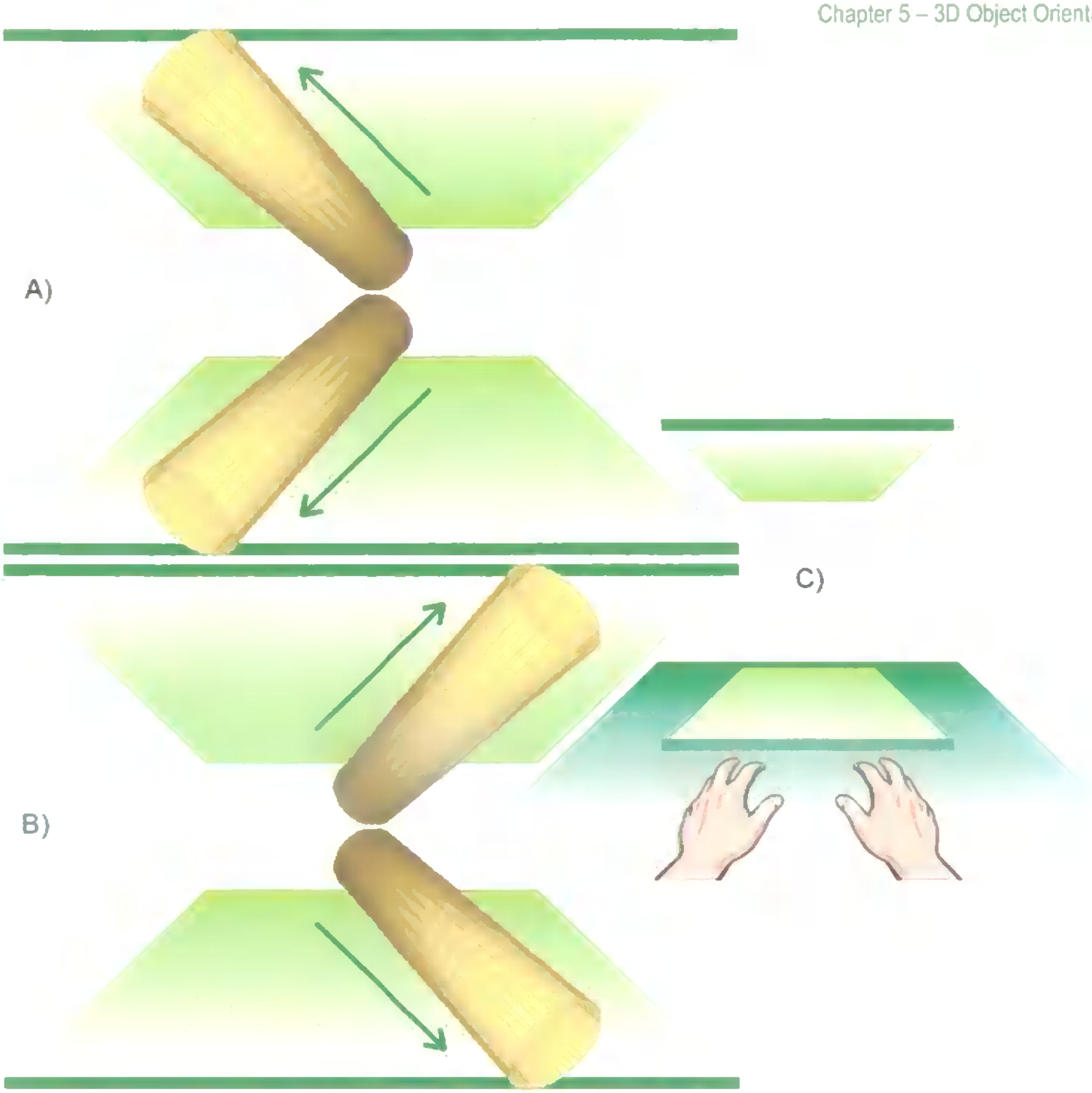


Figure 5.6 The X-Z plane. A) Global cylinder orientations 1 & 3 are shown (as numbered in Figs. 5.1 & 5.2). These are the only two cylinders that share as their common feature a leftwards orientation in the X-Z plane. B) Global cylinder orientations 2 & 4 are shown (as numbered in Figs. 5.1 & 5.2). These are the only two cylinders that share as their common feature a rightwards orientation in the X-Z plane. C) This illustration depicts the X-Z plane to help visualise the dimension under discussion. Note the arbitrary reference point (a thick green line) that allows the definition of leftwards and rightwards orientations through the use of arrowheads that point towards it.

Conventions of reporting and interpreting the data

It should be noted that the cylinder orientation in any plane (e.g. X-Z plane) is *necessarily* specified by the interaction of cylinder orientations in the other two planes (e.g. X-Y × Y-Z planes). For example, a cylinder oriented leftwards in the X-Y plane and downwards in the Y-Z plane, *must*, as a consequence, be oriented leftwards in the X-Z plane. It follows that a main effect of X-Z orientation could alternatively be described as an interaction between X-Y and Y-Z orientation. Indeed, suppose that a significant main effect was found for X-Z orientation [F (1, 18) = 15.005, p < 0.01]. Analysing the data a different way would produce *exactly* the same result [F (1, 18) = 15.005, p < 0.01] for an interaction between X-Y and Y-Z orientations.

This equivalence is illustrated in Figure 5.7A. In examining an interaction between the X-Y and Y-Z planes, the basis for a compatibility effect can be seen with respect to each cylinder that was responded to (see Figure 5.7C). The picture is clearer however (and reveals a more basic phenomenon), when the main effect is considered (see Figure 5.7B). Thus if we look at these cylinders, it can be seen that cylinders 1 & 3 share the common feature of being oriented leftwards in the X-Z plane, whereas cylinders 2 & 4 (which in this example were both responded to considerably faster) share the common feature of being oriented rightwards in the X-Z plane. Consequently, for reasons of conceptual clarity and simplicity, reported results emphasise single planes. For particularly interesting results, both planes are reported. Single planes are reported in the text (e.g. result [5.1.6**a**]) and interacting planes are reported in Appendix 2 (e.g. result [5.1.6**b**]).

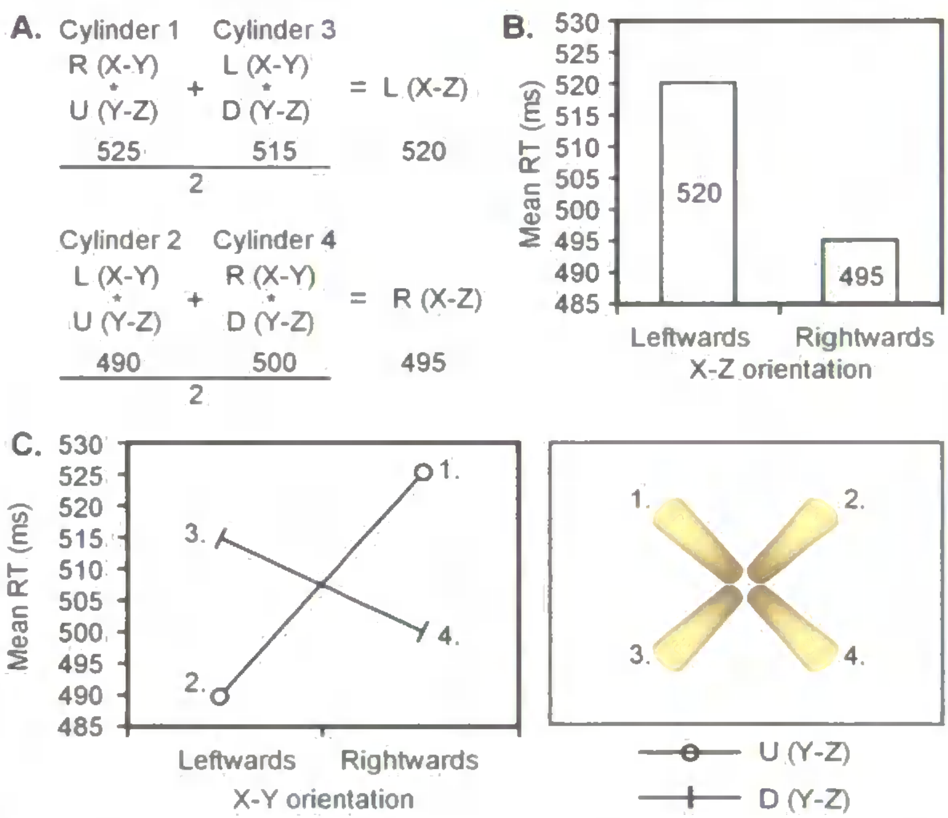


Figure 5.7 A. Example data showing that $[(XY \times YZ)+(XY \times YZ)] \div 2 = XZ$. This data could be expressed as a main effect of X-Z orientation (**B.**), or as an interaction of X-Y × Y-Z (**C.**)

The physical proximity argument

In terms of the 'proximity argument' developed in Chapter 4, it is possible that orientation compatibility effects are sensitive to the physical proximity of a particular end of an object. In terms of the planes described, the edge of a plane that would be closest to the viewer's hands coincided with the arbitrary reference point used. This was done to allow definitions of orientation that were meaningful in terms of viewer-centred action (e.g. left, right, upward, downward), rather than behaviourally neutral terms (e.g. oriented 45°).

While potential effects of cylinder proximity *to the viewer's body* will be apparent within the three individual planes (e.g. for a cylinder oriented leftwards in the X-Z plane, the left end of the cylinder will be closer to the viewer than the right end), it is of interest to investigate whether response performance is influenced by the distance a particular *hand* would have to travel to reach an end of a cylinder. It is therefore notable that the two cylinders oriented downwards in the Y-Z plane (cylinders 3 & 4), are actually closer to a particular hand (in terms of their *global* orientation), whereas the two cylinders oriented upwards in the Y-Z plane (cylinders 1 & 2) are not. This is apparent in Figure 5.8, where it can be seen that *regardless* of which end of the cylinder a hand might hypothetically reach towards (i.e. the closest or the farthest end), there is an overall advantage (in terms of absolute physical proximity of the hands) associated with the left hand for cylinder 3, and the right hand for cylinder 4. Thus if both hands are considered together, overall there is an advantage, in terms of absolute physical proximity, associated with cylinders 3 & 4 (both oriented downwards in the Y-Z plane), when compared to cylinders 1 & 2 (both oriented upwards in the Y-Z plane).

In light of this, the following additional hypothesis can be generated:

Visual Attribute Hypothesis 4: If the absolute physical property of a cylinder contributes to its affordance for components of left-right actions, then a main effect of Y-Z orientation should reflect an advantage for responses made to cylinders oriented downwards in the Y-Z plane.

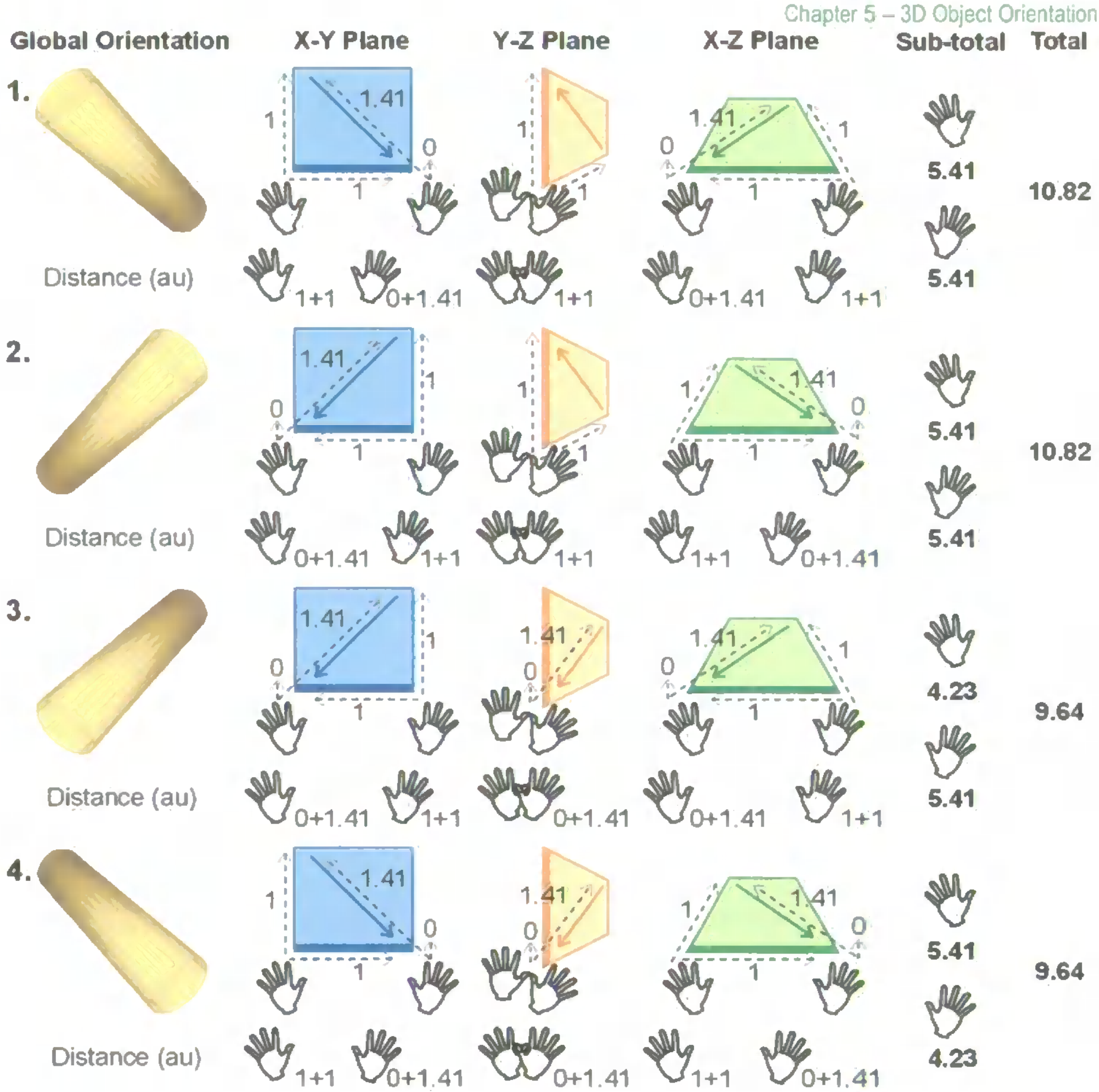


Figure 5.8 Four global cylinder orientations described with respect to their hypothetical physical proximity to the viewer's hands, measured in arbitrary units (au).

5.2.3 Results

Analytical Procedure and Summary Results

Analyses were as described for Experiment 3.1 (correct and incorrect response data sets etc.), but there was only an analysis by participants. Two repeated measures ANOVAs (located in Appendix 1) were performed on the between subjects independent variable of mapping rule, and the within subjects independent variables of hand of response and two of the following: X-Y, Y-Z or X-Z cylinder orientations. Participants were entered as a random factor, and the dependent variables were RTs (the first ANOVA) and mistakes (the second ANOVA). The results for Experiment 5.1 are summarised in Table 5.3. Key results are reported in the text and remaining results are reported in Appendix 2.

Table 5.3 Main effects and interactions reported in Experiment 5.1. Key: statistical significance status (approaching, yes, no). ⌿ depicts results of key theoretical interest.

Result no.	Source	Correct Responses	Incorrect Responses
5.1.1⌿	Y-Z cylinder orientation	No	No
5.1.2	Response	No	Yes
5.1.3⌿	X-Y cylinder orientation × Response	No	App
5.1.4⌿	Y-Z cylinder orientation × Response	No	No
5.1.5	Response × Mapping Rule	Yes	No
5.1.6a⌿	X-Z cylinder orientation × Response	Yes	Yes
5.1.6b	X-Y×Y-Z cylinder orientation × Response	Yes	Yes

Main Effects [5.1.1⌿]

There was no significant main effect of Y-Z cylinder orientation in either RTs [F (1, 18) = 0.218, $p > 0.5$] or mistakes [F (1, 18) = 0.223, $p = 0.5$]. Mean RTs were 475 ms (SE = 8) for cylinders oriented downwards in the Y-Z plane and 476 ms (SE = 8) for cylinders oriented upwards in the Y-Z plane. Mean mistakes were 7.5 % (SE = 0.4) for cylinders oriented downwards in the Y-Z plane and 7.7 % (SE = 0.3) for cylinders oriented upwards in the Y-Z plane. This suggested that overall, the absolute physical proximity of a cylinder to the viewer's hands did not influence response performance (return to section 5.2.2 for an explanation of physical proximity values).

Two-Way Interactions [5.1.3⌿]

There was no significant interaction between X-Y cylinder orientation and hand of response in RTs [F (1, 18) = 1.016, $p > 0.1$]. This suggested that the X-Y orientation of a 3-D cylinder did not have any performance-related benefits (in RTs) associated with spatial key press responses. However, an interaction between X-Y cylinder orientation and hand of response approached significance in mistakes [F (1, 18) = 3.934, $p = 0.063$] (see Figure 5.9). The pattern of means hinted at a negative or reverse compatibility effect. For left hand responses, mean mistakes were 0.7 % fewer for cylinders oriented rightwards rather than leftwards in the X-Y plane. For right hand responses, mean mistakes were 1.7 % fewer for cylinders oriented leftwards rather than rightwards in the X-Y plane.

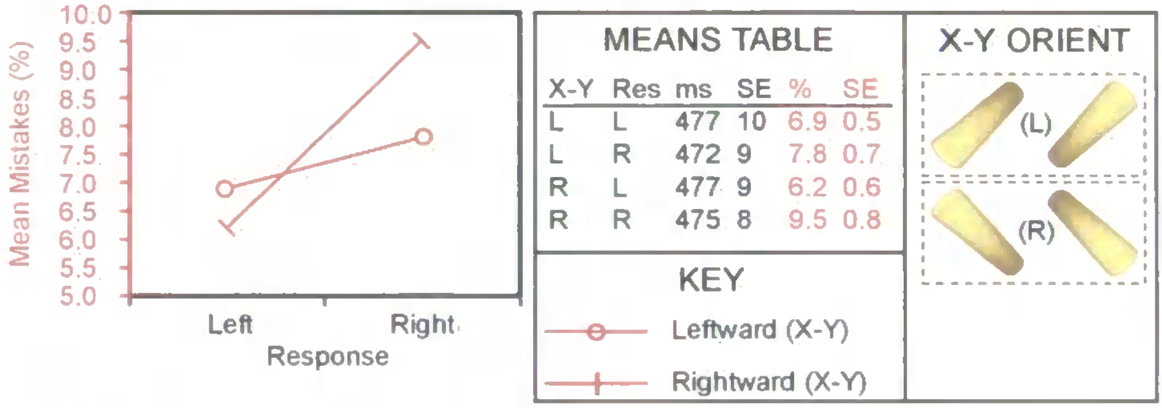


Figure 5.9 Mean mistakes as a function of hand of response and X-Y orientation

Two-Way Interactions [5.1.4 ✓]

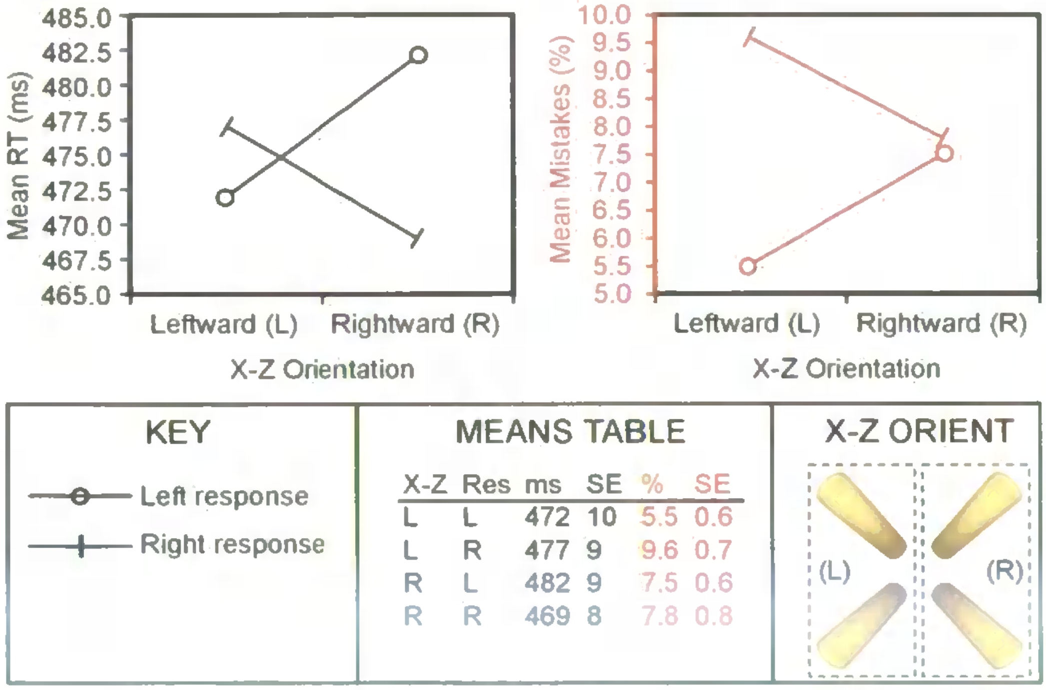
There was no significant interaction between Y-Z cylinder orientation and hand of response in RTs [F (1, 18) = 1.764, $p > 0.1$] or mistakes [F (1, 18) = 0.081, $p > 0.5$]. This suggested that the Y-Z orientation of a 3D cylinder did not have any performance-related benefits associated with spatial key press responses. See Table 5.4 for associated means.

Table 5.4 Means RTs (ms), mistakes (%) and standard errors (SE) for result [5.1.4 ✓]

Y-Z	Res	ms	SE	%	SE
D	L	476	9	6.3	0.5
D	R	474	8	8.7	0.6
U	L	479	9	6.8	0.7
U	R	473	8	8.7	0.7

Two-Way Interactions [5.1.6a ✓]

There was a significant interaction between X-Z cylinder orientation and hand of response in both RTs [F (1, 18) = 17.535, $p = 0.001$] and mistakes [F (1, 18) = 6.511, $p < 0.05$] (see Figure 5.10). For left hand responses, mean RTs were 10 ms faster (and mean mistakes were 2 % fewer) for cylinders oriented leftwards rather than rightwards in the X-Z plane. For right hand responses, mean RTs were 8 ms faster (and mean mistakes were 1.8 % fewer) for cylinders oriented rightwards rather than leftwards in the X-Z plane. This compatibility effect suggested that the X-Z orientation of a 3-D cylinder has performance-related benefits associated with spatial hand key press responses.



X-Z	Res	ms	SE	%	SE
L	L	472	10	5.5	0.6
L	R	477	9	9.6	0.7
R	L	482	9	7.5	0.6
R	R	469	8	7.8	0.8

Figure 5.10 Mean RTs (black) and mean mistakes (red) as a function of hand of response and X-Z orientation

This influence of X-Z orientation on responses can be seen more specifically (in terms of each global cylinder orientation), by examining the equivalent interaction (see Appendix 2, result [5.1.6b]) between Y-Z, X-Z orientation and hand of response.

5.2.4 Discussion

It will be recalled that Experiments 4.1-4.3 consistently failed to produce orientation-action compatibility effects associated with the X-Y plane of 2D diagonal lines. The use of 3D cylinders whose global orientation consisted, in part, of the same orientation in the X-Y plane (45° or 135°) did not conclusively change this pattern. Thus in Experiment 5.1, X-Y cylinder orientation did not influence the performance of compatible responses in RTs, although there was a hint of a negative compatibility effect in mistakes [5.1.3✗]. This suggests that even though the cylinder was 3D, its orientation in the X-Y plane did not afford left-right actions (thus contradicting Visual Attribute Hypothesis 1, which proposed that the most basic property of an object's orientation- its primary axis of elongation in the X-Y plane- is a specific visual attribute that affords left-right actions).

In terms of Y-Z cylinder orientation, support was provided for Visual Attribute Hypothesis 2, in that left-right responses were not differentially influenced by a cylinder's Y-Z orientation [5.1.4✓]. Furthermore, Visual Attribute Hypothesis 4 was not supported, since those cylinders that were physically closer overall to a particular hand (i.e. cylinders oriented downwards) did not produce an advantage; as evidenced by the lack of a main effect of Y-Z orientation [5.1.1✓].

However, in accordance with Visual Attribute Hypothesis 3, orientation in the X-Z plane did appear to afford left-right actions. This was revealed by the orientation-action compatibility effect found in both RTs and mistakes [5.1.6a✓].

In conclusion, this experiment provided preliminary evidence that the X-Z plane was the crucial dimension in which visual cues of orientation afforded left-right actions. It is possible that this visual attribute (i.e. an axis of elongation in the X-Z plane) was the basis for the compatibility effects found with photographs of real objects used in Experiment 3.1 and the studies by Symes (1999), and Tucker and Ellis (1998).

The next experiment investigated the specificity of left-right actions that might be afforded by these cylinders. This was done by examining whether orientation-action compatibility effects (which, in light of the above data, are most likely to be associated with the X-Z plane) were restricted to hand key press responses, or obtainable using spatial power grip responses.

5.3 Experiment 5.2

This experiment addressed whether orientation-compatibility effects were specific to a certain kind of response (e.g. hand key presses), or viable for a range of responses. In particular, the four Action Specificity Hypotheses generated in Chapter 3 were tested (1- a specific action property is afforded that is exclusive to one action; 2- a primitive action property is afforded that is common to many actions; 3- a specific action property is maximally afforded but other action properties are to a lesser extent activated; 4- a range of actions can be afforded by virtue of being physically 'set up' by task parameters).

In testing these hypotheses, Experiment 5.2 investigated left and right hand power grip responses made to the same cylinder stimuli of Experiment 5.1. As these power grip responses mimicked the kind of grasp that would be required to pick up a cylinder, it perhaps had a more intimate coupling with the cylinder than a simple hand key press (that is analogous to the initiation of a reach movement). In this respect, if any differences of response type were to be found between Experiments 5.1 and 5.2, (particularly associated with the X-Z orientation of a cylinder), then it might be expected that these would take the form of a larger orientation-action compatibility effect size for power grip responses. Such a finding would provide support for Action Specificity Hypothesis 3.

5.3.1 Method

Participants

See Experiment 5.1.

Apparatus

As described for Experiment 3.1 (small darkened room, PC etc.), but two graspable power grip response devices were used. Each graspable power grip response device was made from a hinged plastic tube which when squeezed, pressed an inlaid micro switch (see Figure 5.11). These response devices were held in each hand, which rested on the table in front of the monitor.

Materials

See Experiment 5.1.

Design

See Experiment 5.1.

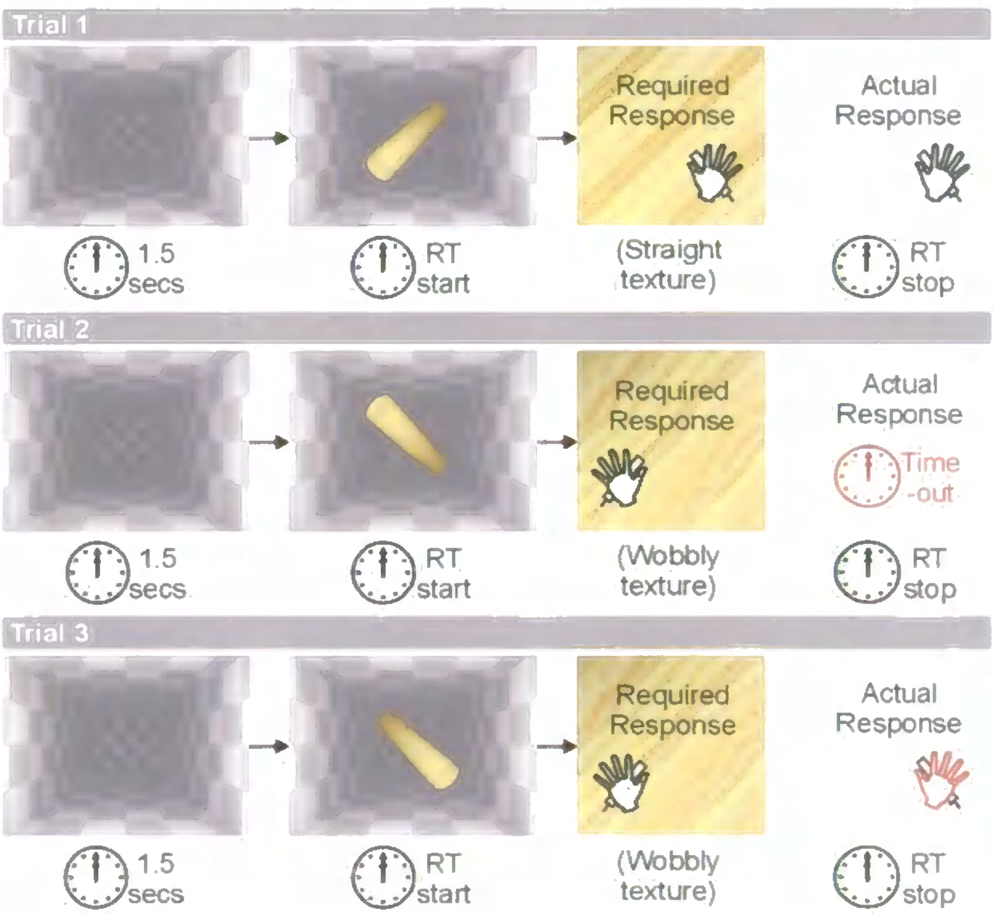
Procedure

As Experiment 5.1, but with power grip responses (see Box 5.2).

Figure 5.11 Response devices for Experiment 5.2

Box 5.2 Trial procedure for Experiment 5.2. The clock icon depicts a millisecond timer, and the hand icon depicts a power grip response. The colour red corresponds to an incorrect response.

The schematic below depicts three typical trials for a participant assigned to MR: C1 (left responses for wobbly cylinder pattern, right responses for straight cylinder pattern). For each trial, the inter-trial stimulus was shown for 1.5 seconds and was then replaced with the target stimulus. A millisecond timer measures the time that the target stimulus remained on the screen. This could be until the participant made a left or right response, or until three seconds had passed and the trial was given time-out. Following the response (or time-out), the target stimulus was immediately replaced with the inter-trial stimulus for a new trial, thus completing the loop.



5.3.2 Results

Analytical Procedure and Summary Results

Analyses were as described for Experiment 3.1 (correct and incorrect response data sets etc.), but there was only an analysis by participants. Two repeated measures ANOVAs (located in Appendix 1) were performed on the between subjects independent variable of mapping rule, and the within subjects independent variables of hand of response and two of the following: X-Y, Y-Z or X-Z cylinder orientations. Participants were entered as a random factor, and the dependent variables were RTs (the first ANOVA) and mistakes (the second ANOVA). The results for Experiment 5.2 are summarised in Table 5.4. Key results are reported in the text and remaining results are reported in Appendix 2.

Table 5.5 Main effects and interactions reported in Experiment 5.2. Key: statistical significance status (approaching, yes, no). ✓ depicts results of key theoretical interest.

Result no.	Source	Correct Responses	Incorrect Responses
5.2.1 ✓	Y-Z cylinder orientation	No	No
5.2.2	X-Y cylinder orientation	No	Yes
5.2.3	Response	No	Yes
5.2.4 ✓	X-Y cylinder orientation × Response	No	No
5.2.5 ✓	Y-Z cylinder orientation × Response	No	No
5.2.6	X-Z cylinder orientation × Mapping rule	App	Yes
5.2.7a ✓	X-Z cylinder orientation × Response	Yes	Yes
5.2.7b	X-Y × Y-Z cylinder orientation × Response	Yes	Yes
5.2.8 ✓	X-Z cylinder orientation × Response × Mapping rule	No	Yes

Main Effects [5.2.1 ✓]

There was no significant main effect of Y-Z cylinder orientation in either RTs [F (1, 18) = 0.115, $p > 0.5$] or mistakes [F (1, 18) = 0.251, $p > 0.5$] (this again suggested that the absolute physical proximity of the cylinder did not influence response performance). Mean RTs were 490 ms (SE = 10) for cylinders oriented downwards in the Y-Z plane and 491 ms (SE = 9) for cylinders oriented upwards in the Y-Z plane. Mean mistakes were 5.4 % (SE = 0.4) for cylinders oriented downwards in the Y-Z plane and 5.7 % (SE = 0.5) for cylinders oriented upwards in the Y-Z plane.

Two-Way Interactions [5.2.4 ✗]

There was no significant interaction between X-Y cylinder orientation and hand of response in either RTs [F (1, 18) = 0.483, $p > 0.1$] or mistakes [F (1, 18) = 3.057, $p > 0.05$]. This suggested that the X-Y orientation of a 3-D cylinder did not have any performance-related benefits (in RTs or mistakes) associated with spatial power grip responses. See Table 5.6 for associated means.

Table 5.6 Means RTs (ms), mistakes (%) and standard errors (SE) for result [5.2.4 ✗]

X-Y	Res	ms	SE	%	SE
L	L	490	10	6.0	0.5
L	R	491	9	6.3	0.6
R	L	488	10	3.8	0.3
R	R	492	9	6.1	0.7

Two-Way Interactions [5.2.5 ✗]

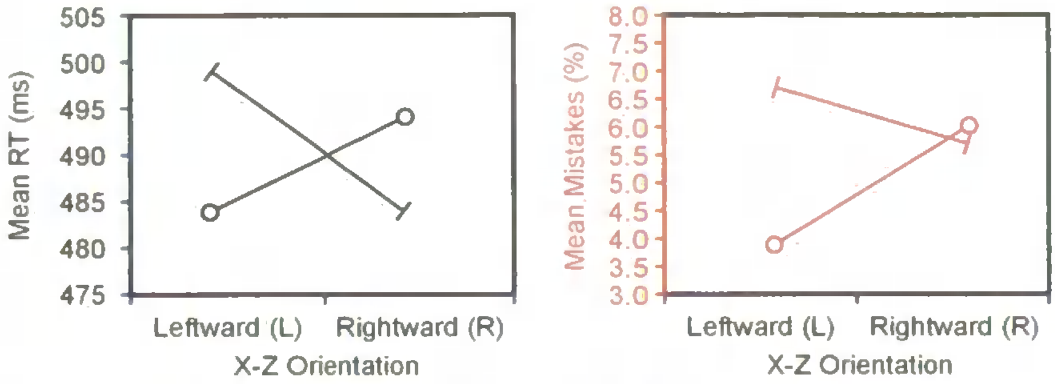
There was no significant interaction between Y-Z cylinder orientation and hand of response in RTs [F (1, 18) = 0.106, $p > 0.5$] or mistakes [F (1, 18) = 0.548, $p > 0.1$]. This suggested that the Y-Z orientation of a 3-D cylinder did not have any performance-related benefits associated with spatial power grip responses. See Table 5.7 for associated means.

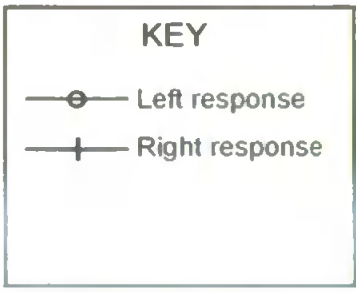
Table 5.7 Means RTs (ms), mistakes (%) and standard errors (SE) for result [5.2.5 ✗]

Y-Z	Res	ms	SE	%	SE
D	L	488	10	4.6	0.5
D	R	491	10	6.3	0.7
U	L	490	10	5.3	0.6
U	R	491	9	6.1	0.6

Two-way interaction [5.2.7a ✗]

There was a significant interaction between X-Z cylinder orientation and hand of response in both RTs [F (1, 18) = 45.509, $p < 0.001$] and mistakes [F (1, 18) = 8.995, $p < 0.01$] (see Figure 5.12). For <u>left hand responses</u>, mean RTs were 10 ms faster (and mean mistakes were 2.1 % fewer) for cylinders oriented leftwards rather than rightwards in the X-Z plane. For <u>right hand responses</u>, mean RTs were 15 ms faster (and mean mistakes were 1 % fewer) for cylinders oriented rightwards rather than leftwards in the X-Z plane. This compatibility effect suggested that the X-Z orientation of a 3-D cylinder had performance-related benefits associated with spatial power grip responses.





MEANS TABLE

X-Z	Res	ms	SE	%	SE
L	L	484	9	3.9	0.5
L	R	499	10	6.7	0.7
R	L	494	10	6.0	0.5
R	R	484	9	5.7	0.6

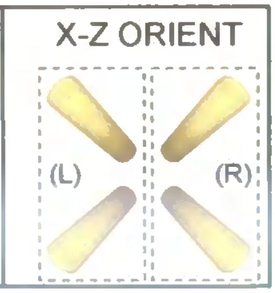


Figure 5.12 Mean RTs (black) and mean mistakes (red) as a function of hand of response and X-Z orientation

This influence of X-Z orientation on responses can be seen more specifically (in terms of each global cylinder orientation), by examining the equivalent interaction (see Appendix 2, result [5.2.7b]) between Y-Z, X-Z orientation and hand of response.

Three-Way Interactions [5.2.8 ✓]

There was a significant interaction between X-Z cylinder orientation, hand of response and mapping rule in mistakes [F (1, 18) = 5.392, $p < 0.05$] but not in RTs [F (1, 18) = 0.806, $p > 0.1$] (see Figure 5.13).

For participants in MR: C1 the interaction between X-Z cylinder orientation and hand of response resembled the compatibility effect observed when collapsed across mapping conditions [5.2.6a ✓]. Thus for left hand responses, mean mistakes were 2.2 % fewer for cylinders oriented leftwards rather than rightwards in the X-Z plane; and for right hand responses, mean mistakes were 3.3 % fewer for cylinders oriented rightwards rather than leftwards in the X-Z plane.

This compatibility effect was not observed however, for participants in MR: C2. Thus for left hand responses, mean mistakes were 2 % fewer for cylinders oriented leftwards rather than rightwards in the X-Z plane. For right hand responses, mean mistakes were 1.3 % fewer for cylinders oriented leftwards rather than rightwards in the X-Z plane.

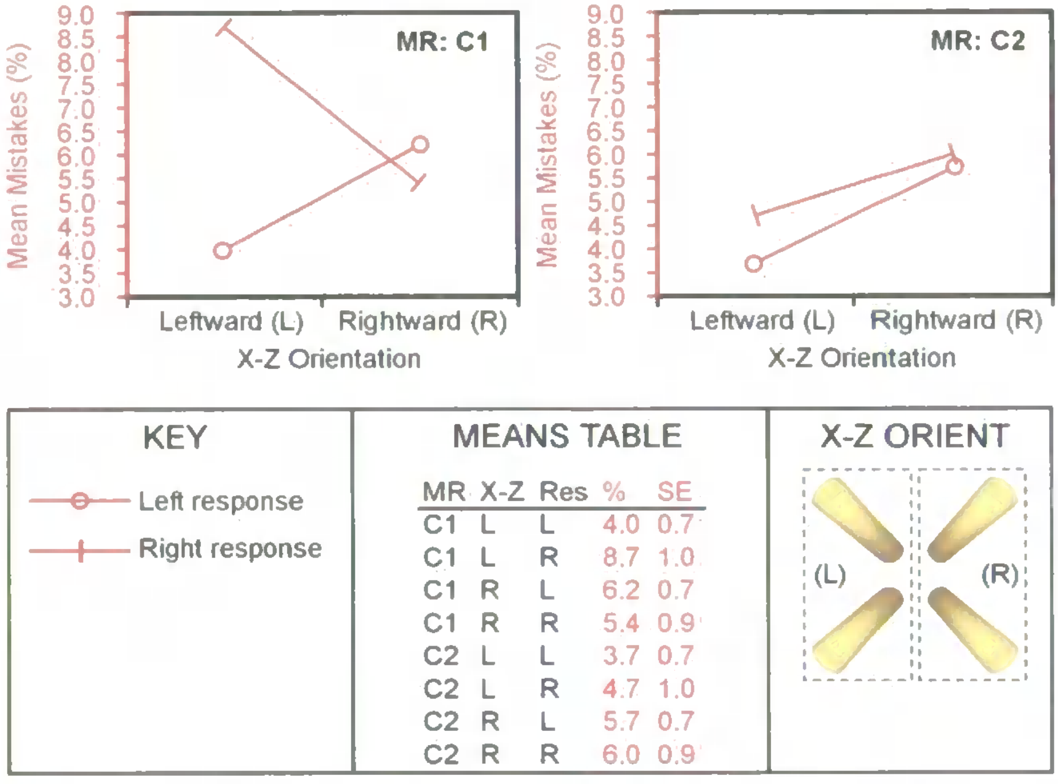


Figure 5.13 Mean mistakes as a function of hand of response, X-Z orientation and mapping rule

5.3.3 Supplementary Results (Experiment 5.1 × 5.2)

In comparing Experiments 5.1 and 5.2, two repeated measures ANOVAs (located in Appendix 1) were performed on the between subjects independent variables of mapping rule and Experiment; and the within subjects independent variables of hand of response and a choice of two of the following: X-Y, Y-Z or X-Z cylinder orientations. Participants were entered as a random factor, and the dependent variables were RTs (the first ANOVA) and mistakes (the second ANOVA). The results for Experiment 5.1 × 5.2 are summarised in Table 5.8.

Table 5.8 Main effects and interactions reported in Experiment 5.1 × 5.2. Key: statistical significance status (approaching, yes, no). ✓ depicts results of key theoretical interest.

Result no.	Source	Correct Responses	Incorrect Responses
Supp 1	Y-Z cylinder orientation	No	No
Supp 2 ✓	Experiment	No	Yes
Supp 3	Response	No	Yes
Supp 4	Response × Mapping rule	Yes	No
Supp 5	X-Y cylinder orientation × Response	No	Yes
Supp 6	Y-Z cylinder orientation × Response	No	No
Supp 7 ✓	X-Y cylinder orientation × Experiment	No	Yes
Supp 8	X-Z cylinder orientation × Response	Yes	Yes
Supp 9 ✓	X-Z cylinder orientation × Response× Experiment	No	No
Supp 10 ✓	X-Z cylinder orientation × Mapping rule× Experiment	No	Yes

On the whole, the results of this supplementary analysis revealed that hand key press responses and power grip responses behaved similarly (i.e. that the results of Experiments 5.1 and 5.2 were statistically similar). Only those results that did suggest differences between the two experiments are reported below.

Main Effects [Supp 2 ✓]

There was a significant main effect of experiment in mistakes [F (1, 36) = 19.457, $p <$ 0.001] but not in RTs [F (1, 36) = 1.436, $p > 0.1$]. Mean mistakes were 2 % fewer in Experiment 5.2 (5.6 %, SE = 0.3) than in Experiment 5.1 (7.6 %, SE = 0.3).

Two-Way Interactions [Supp 7 ✓]

There was a significant interaction between X-Y cylinder orientation and Experiment in mistakes [F (1, 36) = 5.059, $p < 0.05$] but not in RTs [F (1, 36) = 0.286, $p > 0.5$] (see Figure 5.14). For participants in Experiment 5.1, mean mistakes were 0.6 % fewer for cylinders oriented leftwards rather than rightwards in the X-Y plane (this was not a significant main effect in Experiment 5.1). For participants in Experiment 5.2, mean mistakes were 1.2 % fewer for cylinders oriented rightwards rather than leftwards (this was a significant main effect [5.2.2] in Experiment 5.2).

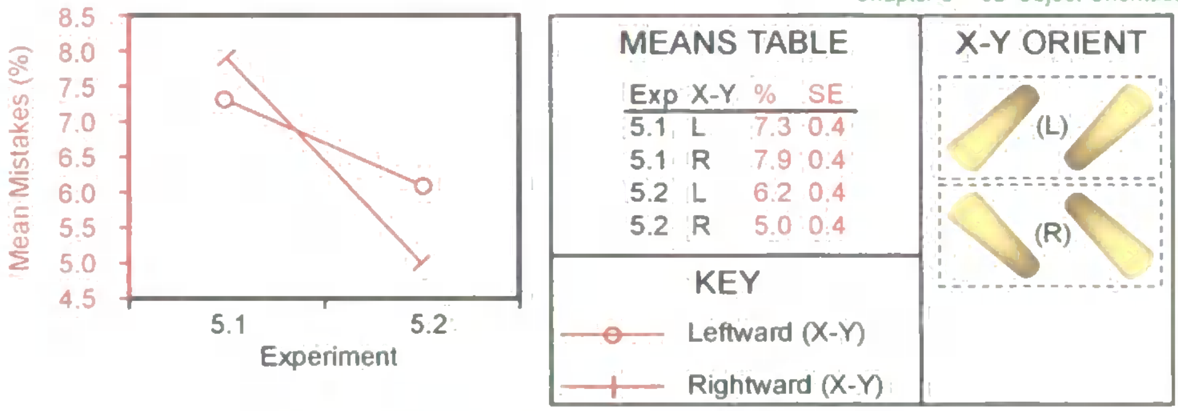


Figure 5.14 Mean mistakes as a function of Experiment and X-Y orientation

Three-Way Interactions [Supp 9 ✓]

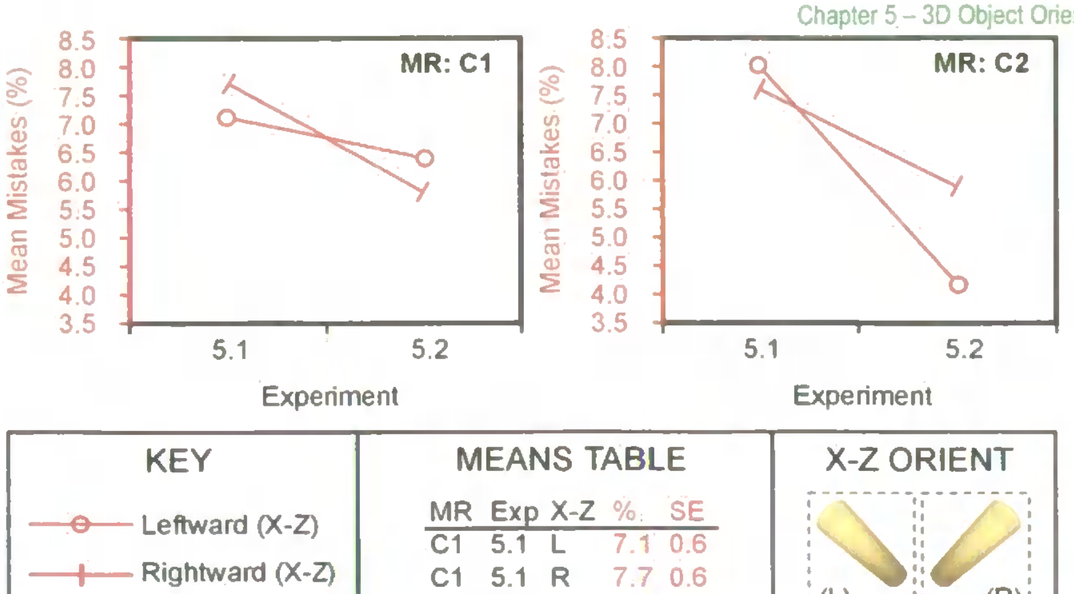
In the crucial comparison, there was no significant interaction between X-Z cylinder orientation, spatial response and Experiment, in either RTs [F (1, 36) = 2.274, $p > 0.1$], or mistakes [F (1, 36) = 0.156, p = 0.5]. This illustrates that there was no significant difference in the size or nature of the compatibility effect between X-Z cylinder orientation and spatial response for the different response types (Experiment 5.1: key press, Experiment 5.2: power grip). See Table 5.9 for associated means.

Table 5.9 Means RTs (ms), mistakes (%) and standard errors (SE) for result [Supp 9 ✓]

Exp	X-Z	Res	ms	SE	%	SE
5.1	L	L	472	9	5.5	0.6
5.1	L	R	477	9	9.6	0.7
5.1	R	L	482	10	7.5	0.5
5.1	R	R	469	8	7.8	0.7
5.2	L	L	484	9	3.9	0.6
5.2	L	R	499	9	6.7	0.7
5.2	R	L	494	10	6.0	0.5
5.2	R	R	484	8	5.7	0.7

Three-Way Interactions [Supp 10 ✓]

There was a significant interaction between X-Z cylinder orientation, mapping rule and Experiment in mistakes [F (1, 36) = 4.976, $p < 0.05$] but not in RTs [F (1, 36) = 0.166, $p >$ 0.5] (see Figure 5.15).



MEANS TABLE

MR	Exp	X-Z	%	SE
C1	5.1	L	7.1	0.6
C1	5.1	R	7.7	0.6
C1	5.2	L	6.4	0.6
C1	5.2	R	5.8	0.6
C2	5.1	L	8.0	0.6
C2	5.1	R	7.6	0.6
C2	5.2	L	4.2	0.6
C2	5.2	R	5.9	0.6

X-Z ORIENT

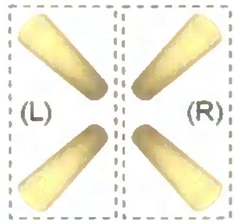


Figure 5.15 Mean mistakes as a function of Experiment, X-Z orientation and mapping rule

The main effect of Experiment reported earlier is apparent in Figure 5.15 (on average, fewer mistakes were made in Experiment 5.2). Apart from this main effect, cylinders oriented rightwards in the X-Z plane did not appear to have been responded to differentially under each mapping condition. However, for cylinders oriented leftwards in the X-Z plane, the following pattern was observed: For participants in Experiment 5.1, mean mistakes were 1 % fewer for participants in MR: C1 rather than MR: C2. For participants in Experiment 5.2, mean mistakes were 2.2 % fewer for participants in MR: C2 rather than MR: C1.

5.3.4 Discussion

Experiment 5.2 essentially reproduced the pattern of results found for Experiment 5.1. Again, Visual Attribute Hypothesis 1 was not supported, since X-Y cylinder orientation did not influence the performance of compatible responses in RTs (and this time, there was no influence evident in mistakes either) [5.2.4✗].

Again, in terms of Y-Z cylinder orientation, support was provided for Visual Attribute Hypothesis 2, in that left-right responses were not differentially influenced by a cylinder's upwards or downwards Y-Z orientation [5.2.5↯]. Furthermore, Visual Attribute Hypothesis 4 was not supported, since those cylinders that were physically closer overall to a particular hand (i.e. cylinders oriented downwards) did not produce an advantage; as evidenced by the lack of a main effect of Y-Z orientation [5.2.1↯].

Again also, in accordance with Visual Attribute Hypothesis 3, orientation in the X-Z plane did appear to afford left-right actions. This was revealed by the orientation-action compatibility effect found in both RTs and mistakes [5.2.7a↯]. This finding did not support Action Specificity Hypothesis 1 (which proposed that a specific action property is afforded that is exclusive to one action) since the X-Z orientation-action compatibility effect has now been found for two different actions, namely hand key presses (Experiment 5.1) and hand power grips (Experiment 5.2). Instead this finding provided some support for Action Specificity Hypothesis 2. Here, an object property (e.g. orientation) might afford a primitive left or right action property that is a common component to many different actions. This finding is also in keeping with Action Specificity Hypothesis 4, whereby an action that is 'set up' (i.e. partially programmed or soft-assembled) will heighten perceptual awareness (in terms of attention) to visual properties of the object (in this case X-Z orientation) that become relevant to that action. In turn that visual property will be more likely to afford the same properties of an action that have been 'set up'.

There was a slight indication of a larger X-Z orientation-action compatibility effect in RTs for power grip responses (the effect size for key presses in Experiment 5.1 was 9 ms, and the effect size for power grips in Experiment 5.2 was 12.5 ms). This might be taken as tentative support for Action Specificity Hypothesis 3 (which proposed that a specific action property is maximally afforded but other action properties are to a lesser extent activated). However, a statistical comparison of the two experiments [Supp 9↯] did not reveal any significant differences between experiments for this effect. This suggested that hand power grips and hand key presses behaved in a similar manner with respect to X-Z cylinder orientation. This finding therefore provided greater support for Action Specificity Hypothesis 2 (which proposed that a primitive action property is afforded that is common to many actions).

In conclusion, this experiment reinforced the proposal that the X-Z plane is the crucial dimension in which visual cues of orientation afford left-right actions. Furthermore, in terms of action specificity, it did not seem to make much difference whether responses were made with key presses or power grips. Bearing in mind the crude response measures of RT and mistakes (which realise very small effects), it is perhaps unrealistic to expect a clear indication of the subtleties of action specificity. Having said this, it is possible that the more distinct the response types are, the greater the likelihood would be of uncovering differences. For example, one response type might be optimal for interacting with the cylinder (e.g. power grip responses) and one might be simply viable within the context of the experiment (e.g. foot responses). The next experiment addressed this possibility.

5.4 Experiment 5.3

This experiment used the same cylinder stimulus set, whilst contrasting (within subjects) two response types. For one half of the experiment foot responses were made, and for the other half of the experiment power grip responses were made. It remained an open question whether foot responses would produce any orientation-compatibility effects, although this possibility seemed likely, bearing in mind the positive results of Experiment 3.1. In assuming that a compatibility effect between X-Z orientation and spatial response (foot responses and power grip responses) might be replicated, the main interest of this experiment concerned whether these two response types would reflect any differences, particularly in the size of the compatibility effects.

5.4.1 Method

Participants

See Experiment 5.1.

Apparatus

The two graspable power grip response devices from Experiment 5.2 were used, and in addition, the response device from Experiment 5.1 was used as a foot response device.

Materials

See Experiment 5.1.

Design

The two dependent variables were RTs and mistakes. The within subjects independent variables were effector (hands, feet), spatial response (left, right), and a choice of two of the following: X-Y cylinder orientation (leftwards, rightwards), Y-Z cylinder orientation (upwards, downwards) or X-Z cylinder orientation (leftwards, rightwards). The between subjects independent variables were mapping rules 1 and 2. Thus the experiment was based on a 2 × 2 × 2 × 2 × 2 × 2 repeated measures design, as illustrated in Table 5.6.

In mapping rule 1: condition 1 (MR1: C1) [n = 10], left spatial responses were made to cylinders with a wobbly surface pattern and right spatial responses were made to cylinders with a straight surface pattern. The 'spatial response-cylinder pattern' pairing was reversed in mapping rule 1: condition 2 (MR1: C2) [n = 10]. In mapping rule 2: condition 1 (MR2: C1) [n = 10], responses were made with the hands for the first half of the experiment and feet for the second half. The order of response effector was reversed in mapping rule 2: condition 2 (MR2: C2) [n = 10].

Table 5.10 Experimental design for Experiment 5.3. Key: mapping rule 1 (MR1), mapping rule 2 (MR2), condition 1 (C1), condition 2 (C2), experimental group (G)

				MR1	
				C1	C2
MR2	C1	Effector	Hands	G_1 (n = 5)	G_2 (n = 5)
			Feet	G_1 (n = 5)	G_2 (n = 5)
		Spatial Response	Left	G_1 (n = 5)	G_2 (n = 5)
			Right	G_1 (n = 5)	G_2 (n = 5)
		X-Y cylinder orientation	Low grasp	G_1 (n = 5)	G_2 (n = 5)
			High grasp	G_1 (n = 5)	G_2 (n = 5)
		Y-Z cylinder orientation	Left grasp	G_1 (n = 5)	G_2 (n = 5)
			Right grasp	G_1 (n = 5)	G_2 (n = 5)
		X-Z cylinder orientation	Left grasp	G_1 (n = 5)	G_2 (n = 5)
			Right grasp	G_1 (n = 5)	G_2 (n = 5)
	C2	Effector	Hands	G_3 (n = 5)	G_4 (n = 5)
			Feet	G_3 (n = 5)	G_4 (n = 5)
		Spatial Response	Left	G_3 (n = 5)	G_4 (n = 5)
			Right	G_3 (n = 5)	G_4 (n = 5)
		X-Y cylinder orientation	Low grasp	G_3 (n = 5)	G_4 (n = 5)
			High grasp	G_3 (n = 5)	G_4 (n = 5)
		Y-Z cylinder orientation	Left grasp	G_3 (n = 5)	G_4 (n = 5)
			Right grasp	G_3 (n = 5)	G_4 (n = 5)
		X-Z cylinder orientation	Left grasp	G_3 (n = 5)	G_4 (n = 5)
			Right grasp	G_3 (n = 5)	G_4 (n = 5)

A practice session consisted of 20 practice trials. The main experiment consisted of 640 trials, divided into 32 blocks of 20 trials. Both cylinder patterns were shown 80 times for each of the four variations of cylinder orientation (thus 80 presentations × 2 patterns × 4 cylinder orientations = 640 trials). The order of cylinder pattern and cylinder orientation was randomised in three blocks (144 + 136 + 360) allowing for the possibility of a balanced analysis at 3 different stages within the experiment[45].

[45] Contrary to the design, this analysis by stages was not actually performed. Instead the experiment was analysed in full. As the order of cylinder pattern and cylinder orientation was not randomised in two blocks of 320 to counterbalance condition instances for hand and foot responses, condition instances varied slightly. However this design flaw was minimal and was not regarded as problematic for the analysis. See Appendix 5 for a table of descriptive statistics relating to condition instances.

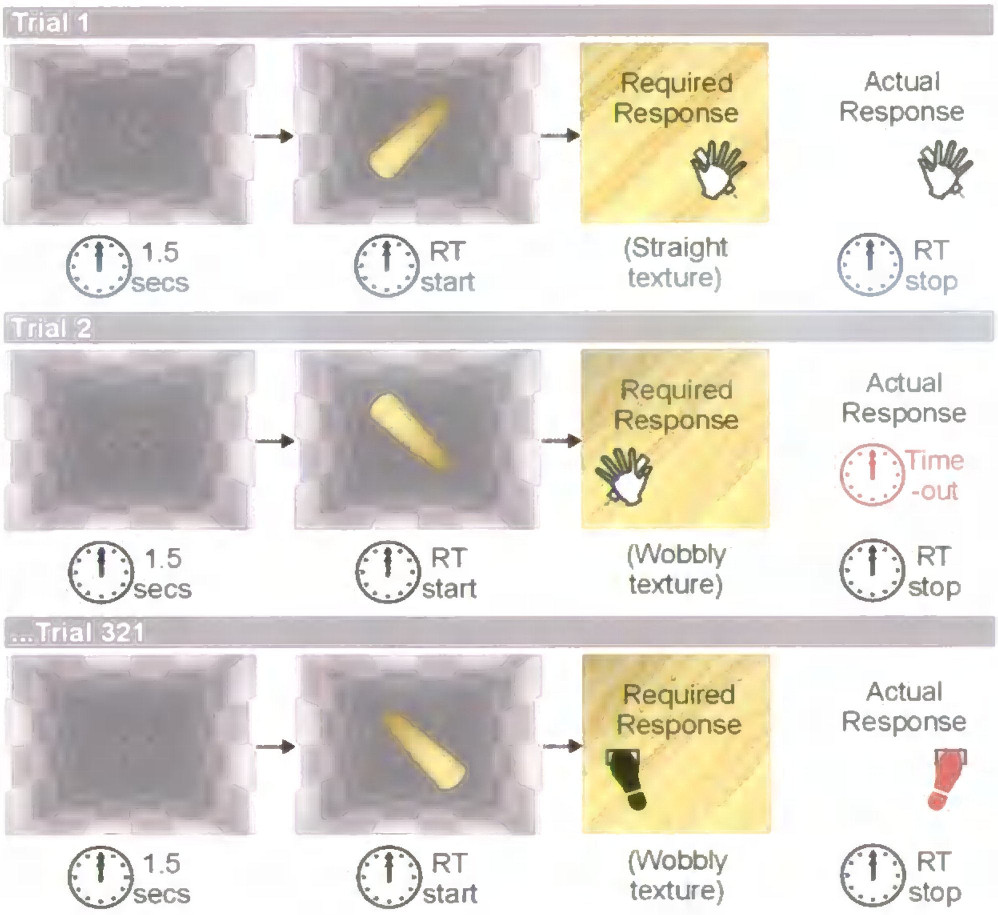
As responses were dependent on the pattern of the cylinder, the independent variables of cylinder orientation (X-Y, Y-Z and X-Z) were task irrelevant.

Procedure

The procedure was the same as Experiment 5.1, with the following exceptions: Participants were pseudo-randomly allocated to an experimental group (Group 1- MR1: C1, MR2: C1; Group 2- MR1: C2, MR2: C2; Group 3- MR1: C1, MR2: C2; Group 4- MR1: C2, MR2: C2). According to their group allocation, they were instructed which order of response effector to use and which spatial response to make to each cylinder pattern. The effector changeover associated with MR2 was signalled on the screen halfway through the experiment, and participants took a short break before resuming the experiment with the newly assigned effectors. After completing the practice session, the main experiment began (which was split into 32 feedback blocks of 20 trials). The trial procedure is outlined in Box 5.4.

Box 5.3 Trial procedure for Experiment 5.3. The clock icon depicts a millisecond timer, the hand icon depicts a power grip response and the shoe icon depicts a foot response. The colour red corresponds to an incorrect response.

The schematic below depicts three typical trials for a participant assigned to MR1: C1 (left responses for wobbly cylinder pattern, right responses for straight cylinder pattern) and MR2: C1 (hand responses for the first half of experiment, foot responses for the second half). For each trial, the inter-trial stimulus was shown for 1.5 seconds and was then replaced with the target stimulus. A millisecond timer measured the time that the target stimulus remained on the screen. This could be until the participant made a left or right (hand or foot) response, or until three seconds had passed and the trial was given time-out. Following the response (or time-out), the target stimulus was immediately replaced with the inter-trial stimulus for a new trial, thus completing the loop.



5.4.2 Results

Analytical Procedure and Summary Results

Analyses were as described for Experiment 3.1 (correct and incorrect response data sets etc.), but there was only an analysis by participants. Two repeated measures ANOVAs (located in Appendix 1) were performed on the between subjects independent variables of mapping rule 1 and mapping rule 2, and the within subjects independent variables of effector, spatial response, and two of the following: X-Y, Y-Z or X-Z cylinder orientation.

The dependent variables were RTs (the first ANOVA) and mistakes (the second ANOVA). The results for Experiment 5.3 are summarised in Table 5.11. Key results are reported in the text and remaining results are reported in Appendix 2.

Table 5.11 Main effects and interactions reported in Experiment 5.3. Key: statistical significance status (approaching, yes, no), mapping rule 1(MR1), mapping rule 2 (MR2). ✓ depicts results of key theoretical interest

Result no.	Source	Correct Responses	Incorrect Responses
5.3.1	Effector	Yes	No
5.3.2	Response	Yes	Yes
5.3.3✓	Y-Z cylinder orientation	Yes	Yes
5.3.4✓	X-Z cylinder orientation	Yes	No
5.3.5✓	X-Y cylinder orientation × Response	No	No
5.3.6✓	Y-Z cylinder orientation × Response	No	No
5.3.7	Effector × MR2	Yes	No
5.3.8	Effector × Response	Yes	No
5.3.9a✓	X-Z cylinder orientation × Response	Yes	Yes
5.3.9b	X-Y × Y-Z cylinder orientation × Response	Yes	Yes
5.3.10	MR1 × MR2 × Y-Z cylinder orientation	No	Yes
5.3.11a✓	Effector × X-Z cylinder orientation × Response	No	Yes
5.3.11b	Effector × X-Y × Y-Z cylinder orientation × Response	No	Yes
5.3.12	MR1 × Effector × X-Y cylinder orientation × Response	Yes	No
5.3.13	MR1 × MR2 × Effector × X-Y cylinder orientation × Response	Yes	No
5.3.14	MR1 × MR2 × Effector × X-Z cylinder orientation × Response	No	Yes

Main Effects [5.3.3✓]

There was a significant main effect of Y-Z cylinder orientation in both RTs [F (1, 16) = 4.928, $p < 0.05$] and mistakes [F (1, 16) = 5.972, $p < 0.05$]. Mean RTs were 4 ms faster (and mean mistakes were 0.8 % fewer), for cylinders oriented upwards (504 ms, SE = 10; 5.5 %, SE = 0.6) rather than downwards (508 ms, SE = 10, 6.3 %, SE = 0.7) in the Y-Z plane. This suggested that when collapsed across hand and foot responses, performance was improved when cylinders were oriented upwards. It is possible that this reflected an effect of the absolute physical proximity of the cylinder. This pattern of mean RTs and mistakes however, did not support Visual Attribute Hypothesis 4. It was predicted that cylinders oriented downwards in the Y-Z plane might be responded to faster and with fewer mistakes, owing to the closer physical proximity of an end of the cylinder to a particular hand. An alternative possibility is that this result reflects a preference for cylinders that would require an upward reach trajectory (perhaps because this is a more comfortable movement).

Main Effects [5.3.4↗]

There was a significant main effect of X-Z cylinder orientation in RTs [F (1, 16) = 5.651, p < 0.05] but not in mistakes [F (1, 16) = 0.017, p > 0.5]. Mean RTs were 4 ms faster for cylinders oriented leftwards (504 ms, SE = 10) rather than rightwards (508 ms, SE = 10) in the X-Z plane. Interestingly, the opposite pattern was reported in Experiment 3.1 [3.1.1↗]; where it was speculated that the predominantly right-handed participants were more perceptually sensitive to objects oriented rightwards in the X-Z plane, by virtue of their long history of interacting with handled objects predominantly with their right hands. The difference between functional objects with handles that have a long history of interaction with the dominant hand (Experiment 3.1) and cylindrical objects with no functional history (Experiment 5.3) may underlie this discrepancy. However, this speculation should be tempered with caution considering that this main effect was very small, and was not observed in Experiments 5.1 and 5.2.

Two-Way Interactions [5.3.5↗]

There was no significant interaction between X-Y cylinder orientation and spatial response in either RTs [F (1, 16) = 0.057, p > 0.5] or mistakes [F (1, 16) = 1.043, p > 0.1]. This suggested that the X-Y orientation of a 3-D cylinder did not have any performance-related benefits (in RTs or mistakes) associated with spatial responses (collapsed across hand power grips and foot key presses). See Table 5.12 for associated means.

Table 5.12 Means RTs (ms), mistakes (%) and standard errors (SE) for result [5.3.5↗]

X-Y	Res	ms	SE	%	SE
L	L	501	10	4.9	0.6
L	R	510	11	7.0	1.0
R	L	503	10	5.2	0.5
R	R	510	11	6.5	0.7

Two-Way Interactions [5.3.6✓]

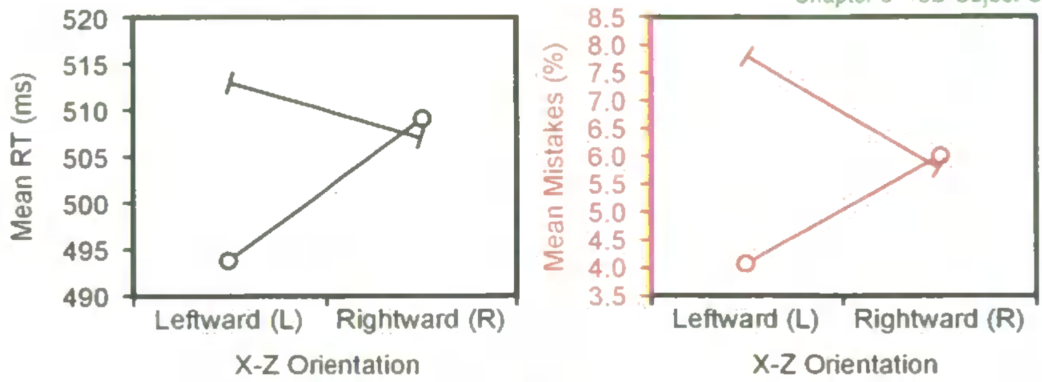
There was no significant interaction between Y-Z cylinder orientation and hand of response in RTs [F (1, 18) = 2.526, $p > 0.1$] or mistakes [F (1, 18) = 0.534, $p > 0.1$]. This suggested that the Y-Z orientation of a 3-D cylinder did not have any performance-related benefits associated with spatial responses (collapsed across power grips and foot presses). See Table 5.13 for associated means.

Table 5.13 Means RTs (ms), mistakes (%) and standard errors (SE) for result [5.1.4✓]

Y-Z	Res	ms	SE	%	SE
D	L	505	10	5.7	0.7
D	R	510	11	6.9	1.0
U	L	499	9	4.5	0.6
U	R	510	11	6.6	0.7

Two-Way Interactions [5.3.9a✓]

There was a significant interaction between X-Z cylinder orientation and spatial response in both RTs [F (1, 16) = 36.011, $p < 0.001$] and mistakes [F (1, 16) = 14.632, $p = 0.001$] (see Figure 5.16). For <u>left spatial responses</u>, mean RTs were 15 ms faster (and mean mistakes were 2 % fewer) for cylinders oriented leftwards rather than rightwards in the X-Z plane. For <u>right spatial responses</u>, mean RTs were 6 ms faster (and mean mistakes were 2 % fewer) for cylinders oriented rightwards rather than leftwards in the X-Z plane. This compatibility effect suggested that the X-Z orientation of a 3-D cylinder had performance-related benefits associated with spatial responses (collapsed across hand power grips and foot key presses). This influence of X-Z orientation on responses can be seen more specifically (in terms of each global cylinder orientation), by examining the equivalent interaction (see Appendix 2, result [5.3.9b]) between Y-Z, X-Z orientation and hand of response.



KEY

- Left response (circle marker)
- Right response (cross marker)

MEANS TABLE

X-Z	Res	ms	SE	%	SE
L	L	494	10	4.1	0.6
L	R	513	11	7.8	1.1
R	L	509	9	6.0	0.5
R	R	507	11	5.8	0.6

X-Z ORIENT

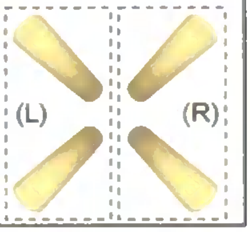


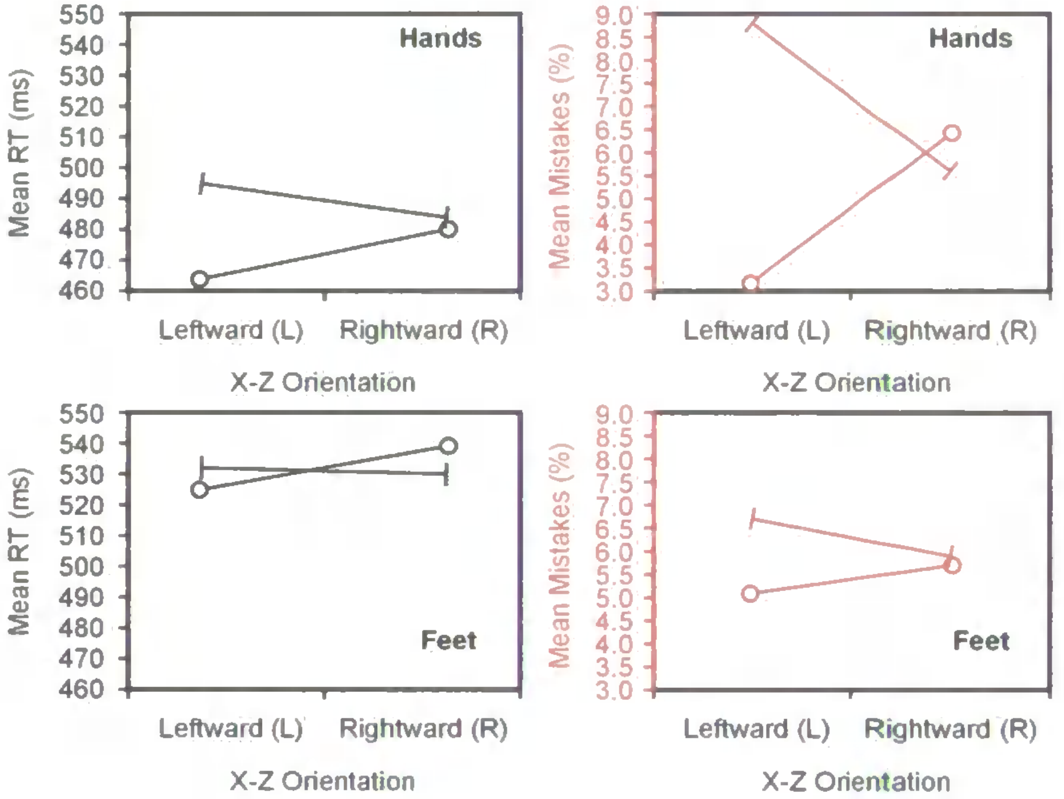
Figure 5.16 Mean RTs (black) and mean mistakes (red) as a function of hand of response and X-Z orientation

Three-Way Interactions [5.3.11a ✓]

There was a significant interaction between effector, X-Z cylinder orientation and spatial response in mistakes [F (1, 16) = 8.771, $p < 0.01$] (see Figure 5.17). For foot responses, the interaction between X-Z cylinder orientation and spatial response followed the usual compatibility pattern: For left foot responses, mean mistakes were 0.6 % fewer for cylinders oriented leftwards rather than rightwards in the X-Z plane. For right foot responses, mean mistakes were 0.8 % fewer for cylinders oriented rightwards rather than leftwards in the X-Z plane.

For hand responses, the interaction between X-Z cylinder orientation and spatial response followed the same pattern, but differences in mean mistakes were larger than those reported for foot responses: For left hand responses, mean mistakes were 3.2 % fewer for cylinders oriented leftwards rather than rightwards in the X-Z plane. For right hand responses, mean mistakes were 3.2 % fewer for cylinders oriented rightwards rather than leftwards in the X-Z plane. This three-way interaction suggested that the X-Z orientation of a 3-D cylinder had performance-related benefits (in mistakes) associated with both types of spatial response (hand power grip and foot key press responses); however, while the compatibility effect held for both response types, the size of the compatibility effect appeared larger for power grip responses rather than foot responses.

In mean RTs, this interaction was not significant [$F(1, 16) = 1.438, p > 0.1$]. Nevertheless, the trend was similar (return to Figure 5.17), with the effect size for power grip responses appearing to be slightly larger (13.5 ms) than that for foot responses (8 ms).



KEY

- ─o─ Left response
- ─┼─ Right response

MEANS TABLE

Eff	X-Z	Res	ms	SE	%	SE
H	L	L	464	9	3.2	0.5
H	L	R	495	10	8.8	1.3
H	R	L	480	9	6.4	0.7
H	R	R	484	10	5.6	0.8
F	L	L	525	12	5.1	0.8
F	L	R	532	13	6.7	1.1
F	R	L	539	11	5.7	0.6
F	R	R	530	13	5.9	0.8

X-Z ORIENT

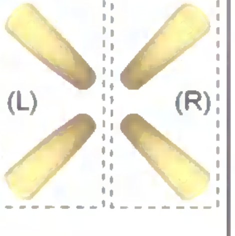


Figure 5.17 Mean RTs (black) and mean mistakes (red) as a function of effector, X-Z orientation and spatial response

5.4.3 Discussion

Experiment 5.3 essentially reproduced the pattern of results found in Experiments 5.1 and 5.2. One anomaly was the finding of a main effect in Y-Z orientation [5.3.3✓], which did not support Visual Attribute Hypothesis 4. This finding showed an advantage in both RTs and mistakes for those cylinders that were physically *farther* overall to a particular hand (that is, cylinders oriented upwards). It is possible that this reflected a preference for object orientations that require an upward rather than downward reach trajectory.

More in line with the two previous experiments however, was the lack of support for Visual Attribute Hypothesis 1, since X-Y cylinder orientation did not influence the performance of compatible responses in RTs or mistakes [5.3.5✓]. Again, in terms of Y-Z cylinder orientation, support was provided for Visual Attribute Hypothesis 2, in that left-right responses were not differentially influenced by a cylinder's upward or downward Y-Z orientation [5.3.6✓].

Again also, in accordance with Visual Attribute Hypothesis 3, orientation in the X-Z plane appeared to afford left-right actions. This was revealed by the orientation-action compatibility effect (collapsed across hand power grips and foot responses) found in both RTs and mistakes [5.3.9a✓].

Of special interest was how this effect played out under each response type. While there was an indication of a larger X-Z orientation-action compatibility effect in RTs for power grip responses (the effect size for foot responses was 8 ms, and the effect size for power grips was 13.5 ms) this interaction between effector, X-Z orientation and spatial response was not statistically significant in RTs [5.3.11a✓]. As such, this finding did not support Action Specificity Hypothesis 1 (which proposed that a specific action property is afforded that is exclusive to one action), but rather supported Action Specificity Hypothesis 2, whereby an object property (e.g. orientation) might afford a primitive left or right action property that is a common component to many different actions. This finding is also in keeping with Action Specificity Hypothesis 4, whereby a compatible action can be 'set up'. The same trend in mistakes however, *was* statistically significant (the effect size for foot responses was 0.7 %, and the effect size for power grips was 3.2 %). This result suggested that X-Z cylinder orientation had a greater magnitude of influence on power grips than on foot responses. This significant result in mean mistakes can be taken as support for Action Specificity Hypothesis 3 (which proposed that a specific action property is maximally afforded but other associated action properties are to a lesser extent activated).

In conclusion, this experiment again reinforced the proposed hypothesis that the X-Z plane was the crucial dimension in which visual cues of orientation afford action. Furthermore, it revealed differences in the extent to which orientation in the X-Z plane affected foot responses and power grips. While a trend that suggested a more powerful affordance for power grip responses (as opposed to foot responses) was consistent for both performance measures, it was only statistically significant for mean mistakes. These results therefore provided only partial support for the idea of spreading activation in a distributed perception-action network (where activation is strongest for the actual affordance, and weaker for associated action properties). As argued previously, this finding is also consistent with the possibility that the physical parameters of a task can 'set up' (i.e. partially program or soft assemble) compatible responses. Thus actions that apparently have no natural coupling with an object's orientation (such as foot responses) can promote themselves as viable couplings if they are 'set up' within the physical context of the task.

5.5 General Discussion of Experiments 5.1- 5.3

Experiments 5.1-5.3 investigated which specific dimension or dimensions of an object's orientation might afford components of left-right actions, and how specific these afforded action components might be. In terms of visual attributes, it was consistently shown that cylinder orientation in the X-Y plane, when examined in isolation, did not produce orientation-action compatibility effects, regardless of what kind of left-right response was made (i.e. hand key presses, foot key presses or hand power grips). Overall, orientation in the X-Y plane has not appeared to be a basic visual attribute that affords components of left-right actions, regardless of whether this visual attribute belonged to 2D lines (Experiments 4.1-4.3) or 3D cylinders (Experiments 5.1-5.3).

Similarly, in Experiments 5.1-5.3, it was consistently shown that cylinder orientation in the Y-Z plane, when examined in isolation, did not produce orientation-action compatibility effects; again regardless of what kind of left-right response was made (i.e. hand key presses, foot key presses or hand power grips). This finding is easily attributed to the fact that a cylinder oriented upward or downward in the Y-Z plane would not offer an advantage for either left or right responses owing to a mismatch of spatial dimension.

Perhaps of most interest was the finding that cylinder orientation in the X-Z plane, when examined in isolation, consistently produced orientation-action compatibility effects. This suggested that when purely visual cues of orientation were provided (i.e. they are not confounded with functional connotations, such as those associated with the handle of a saucepan say), it was the orientation of an object in the X-Z plane that was most relevant for action.

Furthermore, this relevance for action was not restricted to the most obvious left-right actions (e.g. hand responses analogous to the initiation of a reach or power grip responses analogous to a grasp), but also for left-right actions that had little obvious relevance to an object's orientation (e.g. foot responses). It was not entirely clear from the data whether this range of actions was differently affected. There was a trend in the data that suggested a continuum of influence; with the least affected responses being foot responses, then hand key presses, and the most affected responses being hand power grip responses. The only statistically significant support for this trend however, resided in the difference in mean mistakes between foot responses and hand power grip responses.

Thus there was not conclusive evidence to favour either a hypothesis that related to visuomotor primitives that are common to many actions (and should therefore influence each action to a similar degree); or a hypothesis that related to a distributed perception-action network reflecting different strengths of association. Similar to this latter hypothesis is TEC's 'feature-weighting principle' that allows these same visuomotor primitives (or feature codes) to be weighted more or less highly depending on the current relevance for action (that is in part determined by goals, intentions, attention and a history of associations). Consistent with all these ideas, was the possibility that a physical and intentional preparedness to perform a certain action or actions (as was the case for a participant who was required to make left or right responses), will 'set up' attention to select those visual properties of an object that are relevant to the partially prepared action.

Revisiting 'the middle way'

The findings reported above are consistent with the more general notion of an action-oriented representation (that has been the focus of much discussion in previous chapters). Thus the data is consistent with the idea that in coding a purely visual attribute of an object (i.e. the orientation of its primary axis of elongation in the X-Z plane), there is a simultaneous coding of the components of actions that might be relevant to that visual attribute (i.e. left-right action properties). This might be described as a 'representational default setting', as orientation was a task-irrelevant object property. Although a visual attribute affordance may relate to aspects of a specific action (e.g. a power grip), the actual motor basis for this affordance actually appears to be quite abstract, under specified or primitive (such that it might be a common component of many actions). This complements the widespread move away from highly detailed and fully specified notions of representation that was discussed at length in Chapter 1.

In keeping with this, the data here supports the views held by those approaches that adopt 'the middle way' (see Chapter 2). To take the Enactive Approach as an example, it has been argued that the business of persisting as an organism consists of the taking of suboptimal rather than optimal solutions. Structural couplings (cf. perception-action couplings) need only be viable; otherwise the interactions of a system (e.g. the vision-action system) would have to be more or less *prescribed.* Consequently, by having action-oriented representations that operate at a fairly abstract level (such as TEC's common representational domain), the properties of action that an object might afford are not rigidly prescribed (e.g. the X-Z orientation of an object will not activate a highly specialised motor component that is exclusive to a particular grip type); but instead are loosely constrained such that a range of possible actions might benefit (e.g. even left-right foot responses).

This 'viability function' of an action-oriented representation should not be taken to mean that anything goes. Instead it can be argued that some action properties are more viable than others. Thus, when foot responses are the most relevant context for interacting with an object, then the most appropriate of these foot responses (e.g. a left foot response) will hold the advantage. Nevertheless, this left foot response is not *the* optimal action since under different circumstances one could make a more compatible action (e.g. a left power grip). To clarify this point, it is helpful to consider an analogy made by Varela et al. (1992, p. 194),

> "John needs a suit. In a fully symbolic and representationalist world, he goes to his tailor who measures him and produces a nice suit according to the exact specifications of his measurements. There is, however, another possibility, one that does not demand so much from the environment. John goes to several department stores and chooses a suit that fits well from among the various ones available. Although these do not suit him exactly, they are good enough, and he chooses the optimal one for fit and taste. Here we have a good selectionist alternative that uses some optimal criteria of fitness. The analogy admits, however, of further refinement. John, like any human being, cannot buy a suit in isolation from the rest of what goes on in his life. In buying a suit, he considers how his looks will affect the response of his boss at work, the response of his girlfriend, and he may also be concerned with political and economic factors. Indeed, the very decision to buy a suit is not given from the outset as a problem but is constituted by the global situation of his life. His final choice has the form of satisfying some very loose constraints (e.g. being well dressed) but does not have the form of a fit- and even less so of an optimal fit- to any of these constraints."

However, the purpose of a controlled experimental setting is precisely to limit as many unwanted constraints as possible. Choices, therefore, are restricted to a minimum (e.g. a binary response decision is made to a binary stimulus distinction). In this respect, 'a good selectionist alternative', if somewhat oversimplified, may adequately explain the data.

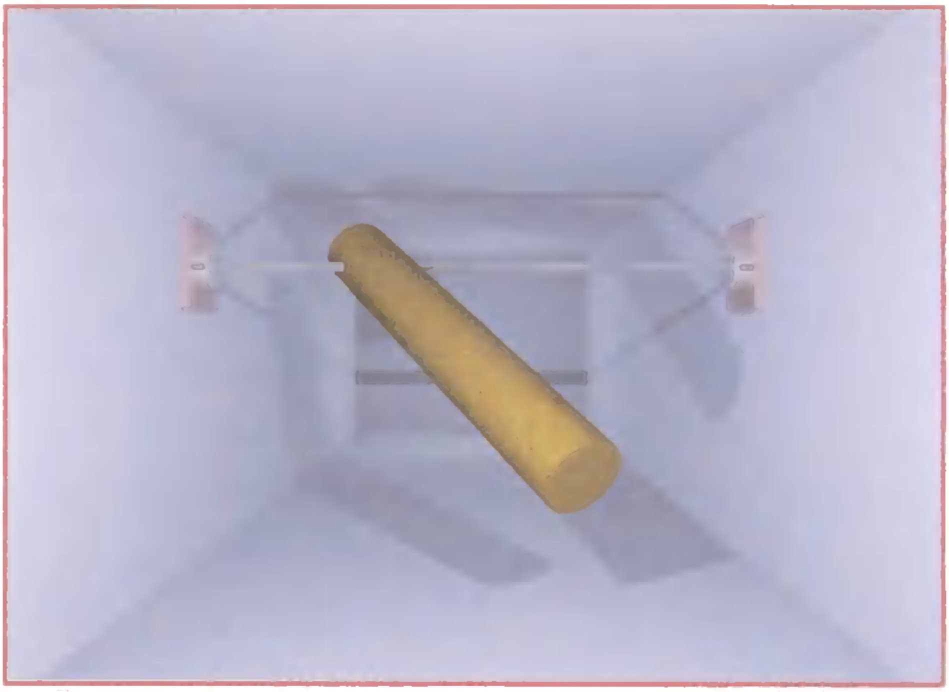
Thus from the available options, a left foot response (that obeys the mapping rule and that is afforded by a visual attribute of leftwards X-Z orientation) serves as the optimal choice, and this is reflected in speed and accuracy.

Having said this however, there do remain several experimenter and self-imposed task constraints (speed, concentration, fatigue levels, accuracy in terms of the mapping rule and accuracy in terms of being centred over a button, comfort such that a response is not too hard but not so soft as to fail to depress the key etc.). The actual response to a given cylinder will reflect the satisfying of some of these constraints. Some constraints will be satisfied better than others, and some of these constraints will be relaxed or loosened (e.g. speed may be relaxed in favour of accuracy, or vice versa- as is sometimes evidenced by speed/accuracy trade-offs in RT studies). Thus in terms of an afforded action property, seeing the cylinder does not predetermine the execution of an optimal response (in which case we would be fully stimulus-driven agents); but rather, merely *triggers* the activation of a viable visuomotor primitive (or set of visuomotor primitives) that will ensure a small advantage for (among other things) a compatible foot response. The execution of this response is actually *determined* by multiple constraint satisfaction.

Indeed, it may be useful to consider a proposed visuomotor primitive (or abstract feature code) as a loose constraint itself. Rather than an affordance that evokes a comprehensive and detailed action plan (such as all the parameters involved in making an optimal reach to an object), a far less demanding solution would be an affordance that evokes a loosely constrained and elemental action plan that can be recruited by a range of different actions. These subtleties have interesting implications for what Ellis and Tucker (2000) have termed 'micro-affordances' (the terminology of which makes a good deal of sense given the above).

One way of demonstrating that a micro-affordance is loosely constrained rather than fixed and prescribed would be to show that the same (or at least structurally similar) visual stimulus that had previously evoked what might be described as a 'representational default setting', could, under different circumstances, produce *different* perception-action compatibility effects. For example, one might find that a different task context realises orientation-action compatibility effects associated with the X-Y or Y-Z planes (which, as we have seen, are not produced by default); or that the pattern of orientation-action compatibility effects associated with X-Z plane (which, as we have seen, are produced by default) could be changed in some way (e.g. modulated, overridden or elaborated). In light of the above suggestions, where Experiments 5.1-5.3 have been interpreted as revealing a 'default' affordance for left-right actions associated with the purely visual attribute of X-Z orientation; the experiments in the next chapter investigated whether this default could be changed or added to (with the appearance of new compatibility effects) by manipulating the task context whilst leaving the basic structure of the oriented cylinder in tact.

6. Perception-action couplings and task context



Contents

6.1 Experimental Hypotheses and Overview

Objective 4: To develop Objective 3 further by exploring how the orientation-action compatibility effects established in Chapter 5 might be modulated by various task manipulations that include stimulus onset asynchrony, apparent motion and participation in an ongoing dynamic activity (see Experiments 6.1 – 6.3).

This chapter follows on from Chapter 5 by addressing whether the introduction of different experimental contexts might change the nature of the previously established 'representational default' (i.e. the compatibility effect associated with X-Z cylinder orientation) and/or whether any new compatibility effects might arise. The impetus behind this line of enquiry comes from the idea that action-oriented representations are not rigidly prescribed, but are loosely constrained such that they can be modulated, elaborated or overridden. This idea is wholly complementary to the various 'middle way' approaches discussed throughout this thesis.

Under most circumstances where there is no specific goal to interact with an object (i.e. simply viewing an object), it might be expected that 'representational defaults' are automatically activated. This source of default affordance (a loose constraint) serves to keep a variety of options open with respect to potential actions (e.g. as we have seen in Chapter 5, it can influence a range of different actions, possibly by virtue of common visuomotor primitives). However, there are numerous task manipulations that one might conceive of that change the emphasis of a stimulus or a response (even when one is 'simply viewing' an object). Under these circumstances, while a representational default may (or may not) remain activated, *other* information may present itself as a source of (non-default) affordance. Thus it can be speculated that these additional sources of information (that become relevant to action thanks to the new task context) may result in new perception-action compatibility effects (in addition to those associated with representational defaults). In addition, they may cause the *tightening of constraints* through the modulation or elaboration of a default (such that the nature of its influence on components of an action changes), or they may actually override a representational default (such that it no longer exerts an influence on components of an action).

In investigating these rather open-ended possibilities, this last experimental chapter was quite exploratory in nature. The manipulations chosen were varied (Experiment 6.1: SOA's; Experiment 6.2: apparent motion; Experiment 6.3: participation in an ongoing dynamic activity) and predominantly served as stand-alone experiments. Bearing this exploratory feel in mind, no specific hypotheses have been formulated. Instead the following broad hypothesis will suffice:

Task Context Hypothesis: In changing the context of a task (by using manipulations such as SOA, apparent motion and involvement in a dynamic activity), it is predicted that a) new perception-action compatibility effects may be revealed, and/or b) previously established perception-action compatibility effects may be altered in some way.

In testing this Task Context Hypothesis, Experiments 6.1-6.3 manipulated aspects of the basic cylinders used in the previous chapter (crucially however, without changing their global orientations). Responses were either spatial power grips (Experiments 6.1 & 6.2) or spatial hand key presses (Experiment 6.3). The results of all three experiments supported predictions a) and/or b) of the Task Context Hypothesis.

In using SOA's that varied the time between stimulus presentation and response execution (Experiment 6.1), a *new* compatibility effect associated with X-Y cylinder orientation and response was revealed; whereas the familiar 'default' affordance associated with X-Z cylinder orientation and response remained unaffected by different SOA's.

In making a cylinder apparently move towards the viewer (Experiment 6.2), the familiar 'default' affordance associated with X-Z cylinder orientation disappeared.

In making a cylinder part of a functioning lever-like device (Experiment 6.3), a previously established 'default' affordance associated with a main effect of Y-Z cylinder orientation was elaborated (such that its possible function of affording upward reach trajectories interacted in a transparent manner with the mechanics of the lever). Furthermore, the familiar 'default' affordance associated with X-Z cylinder orientation was modulated (such that the direction of the compatibility effect was reversed to accommodate a more appropriate lever-contingent action). Finally a *new* and remarkably intricate compatibility effect was revealed that was in part associated with Y-Z cylinder orientation.

It was concluded that these various sources of evidence supported the Task Context Hypothesis, the cumulative impact of which suggested that the affordance-like effects observed were *not* rigidly prescribed, but appeared to be loosely constrained such that under certain circumstances they could be modulated, elaborated or even overridden or eradicated. In addition, it was concluded that despite using visually similar stimuli (that always maintained a cylinder's global orientation), the introduction of different task contexts had the effect of opening up different sources of affordance for the perceiver-actor.

6.2 Experiment 6.1

A crucial design consideration in testing the Task Context Hypothesis was to keep the visual stimuli as similar as possible to the cylinders used in Chapter 5. In this way it could be assumed that any changes in the data did not reflect the influence of the stimuli themselves (in particular their global orientations), but rather how the new task context had changed the way in which participants perceived these stimuli.

One obvious manipulation was to use the same stimuli, while controlling the time before response that participants looked at them. Indeed, as was mentioned in Chapter 4, Tucker & Ellis (2001) reported a statistically significant trend in the time course of their compatibility effects (compatibility between object size and grip type). The longer the RTs were (and hence the more time spent looking at the objects), the greater the size the compatibility effect was. It was therefore a possibility that the established and reliable compatibility effect between X-Z cylinder orientation and spatial response (as reported in Chapter 5) might have increased in size as viewing times increased. However, it is possible (if not likely), that the time course results of Tucker & Ellis (2001) were simply an artefact of RTs revealed by the distributional analyses (see Zhang & Kornblum, 1997 for a detailed critique of distributional analyses). Using the technique of SOA tested *directly* whether the time of viewing changed the nature of responses, thus avoiding the considerations of distributional analysis.

6.2.1 Method

Participants

As described for Experiment 3.1 (undergraduate volunteers etc.), but 20 participants took part.

Apparatus

As described for Experiment 3.1 (small darkened room, PC etc.), but two graspable power grip response devices (from Experiment 5.2) were used.

Materials

The stimulus set was the same as that described for Experiment 5.1. In addition, for each global cylinder orientation there was a version with a neutral surface pattern (see Figure 6.1).

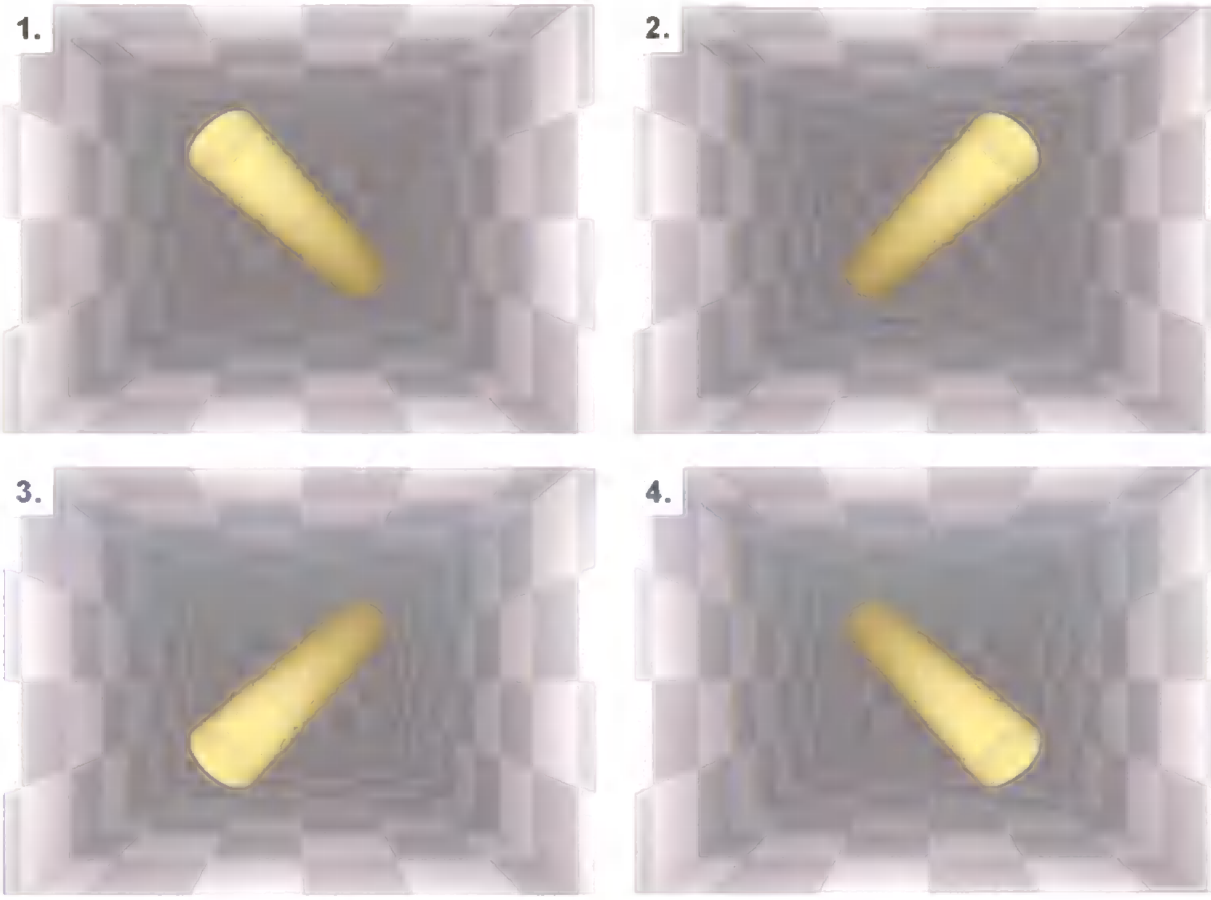


Figure 6.1 The four global orientations of cylinders used in Experiment 5.1. Only cylinders with a neutral surface pattern are shown.

Design

The two dependent variables were RTs and mistakes. The within subjects independent variables were delay (0 ms, 400 ms, 800 ms), hand of response (left, right), and a choice of two of the following: X-Y cylinder orientation (leftwards, rightwards), Y-Z cylinder orientation (upwards, downwards) or X-Z cylinder orientation (leftwards, rightwards). The between subjects independent variable was mapping rule. Thus the experiment was based on 3 × 2 × 2 × 2 × 2 repeated measures design, as illustrated in Table 6.1.

Table 6.1 Experimental design for Experiment 6.1. Key: mapping rule (MR), condition 1 (C1), condition 2 (C2), experimental group (G)

		MR	
		C1	C2
Delay	0 ms	G_1 (n = 10)	G_2 (n = 10)
	400 ms	G_1 (n = 10)	G_2 (n = 10)
	800 ms	G_1 (n = 10)	G_2 (n = 10)
Response	Left hand	G_1 (n = 10)	G_2 (n = 10)
	Right hand	G_1 (n = 10)	G_2 (n = 10)
X-Y cylinder orientation	Left grasp	G_1 (n = 10)	G_2 (n = 10)
	Right grasp	G_1 (n = 10)	G_2 (n = 10)
Y-Z cylinder orientation	Low grasp	G_1 (n = 10)	G_2 (n = 10)
	High grasp	G_1 (n = 10)	G_2 (n = 10)
X-Z cylinder orientation	Left grasp	G_1 (n = 10)	G_2 (n = 10)
	Right grasp	G_1 (n = 10)	G_2 (n = 10)

In mapping rule: condition 1 (MR: C1) [n = 10], left hand responses were made to cylinders with a wobbly surface pattern and right hand responses were made to cylinders with a straight surface pattern. The 'hand of response-cylinder pattern' pairing was reversed in mapping rule: condition 2 (MR: C2) [n = 10]. A practice session consisted of 20 overt practice trials. The main experiment consisted of 600 trials, divided into 30 blocks of 20 trials. Both cylinder patterns were shown 75 times for each of the four global cylinder orientations (thus 75 presentations × 2 patterns × 4 global cylinder orientations = 600 trials). In each trial, for each patterned cylinder shown, its counterpart neutrally patterned cylinder was also shown. The order of cylinder pattern and global cylinder orientation was randomised in three blocks of 200 (one block for each of the three delays). As responses were dependent on the pattern of the cylinder, the independent variables of delay and cylinder orientation (X-Y, Y-Z and X-Z) were task irrelevant.

Procedure part a (general procedure)

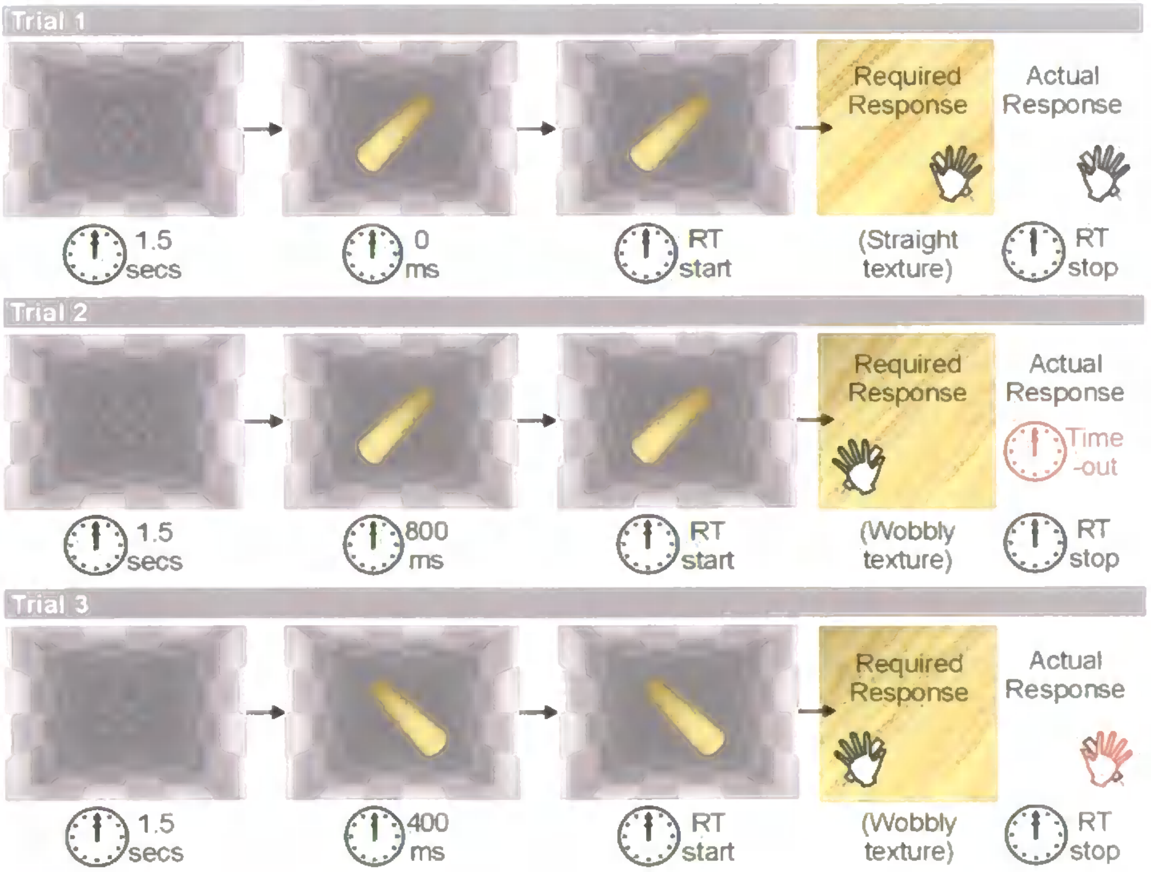
As described for Experiment 3.1 (consent forms, general instruction of fast and accurate responses etc.).

Procedure part b (trial procedure)

Participants were pseudo-randomly allocated to an experimental group (Group 1- MR: C1, Group 2- MR: C2). According to their group allocation, they were instructed which hand to respond with for the two cylinder patterns (wobbly and straight). In addition, participants were warned to expect on some trials a cylinder with a neutral surface pattern that would change to wobbly or straight after an unspecified time (the replacement of the neutral patterned cylinder with a wobbly or straight patterned cylinder was perceived as the cylinder remaining on screen with just its pattern changing). After completing the practice session, the main experiment began. The trial procedure is outlined in Box 6.1.

Box 6.1 Trial procedure for Experiment 6.1. The clock icon depicts a millisecond timer, and the hand icon depicts a power grip response. The colour red corresponds to an incorrect response.

The schematic below depicts three typical trials for a participant assigned to MR: C1 (left responses for wobbly cylinder pattern, right responses for straight cylinder pattern). For each trial, the inter-trial stimulus was shown for 1.5 seconds and was then replaced with the delay stimulus (a neutral patterned cylinder) that was shown for 0, 400 or 800 ms. The delay stimulus was then replaced with the target stimulus (patterned cylinder). A millisecond timer measured the time that the target stimulus remained on the screen. This could be until the participant made a left or right response, or until three seconds had passed and the trial was given time-out. Following the response (or time-out), the target stimulus was immediately replaced with the inter-trial stimulus for a new trial, thus completing the loop.



Procedure part c (feedback routine)

The feedback routine was the same as that described for Experiment 5.1 (two progress charts). There were 30 feedback blocks, each consisting of 20 trials.

6.2.2 Results

Analytical Procedure and Summary Results

Analyses were as described for Experiment 3.1 (correct and incorrect response data sets etc.), but there was only an analysis by participants. Two repeated measures ANOVAs (located in Appendix 1) were performed on the between subjects independent variable of mapping rule, and the within subjects independent variables of delay, hand of response and two of the following: X-Y, Y-Z or X-Z cylinder orientations. Participants were entered as a random factor, and the dependent variables were RTs (the first ANOVA) and mistakes (the second ANOVA). The results for Experiment 6.1 are summarised in Table 6.2. Key results are reported in the text and remaining results are reported in Appendix 2.

Table 6.2 Main effects and interactions reported in Experiment 6.1. Key: statistical significance status (approaching, yes, no). ⌿ depicts results of key theoretical interest.

Result no.	Source	Correct Responses	Incorrect Responses
6.1.1 ⌿	Y-Z cylinder orientation	No	No
6.1.2	X-Y cylinder orientation	Yes	No
6.1.3	Delay	Yes	No
6.1.4	Response	No	Yes
6.1.5	Mapping rule × Response	No	Yes
6.1.6	Mapping rule × Delay	Yes	No
6.1.7	Mapping rule × X-Z cylinder orientation	No	Yes
6.1.8 ⌿	X-Y cylinder orientation × Response	Yes	No
6.1.9 ⌿	Y-Z cylinder orientation × Response	No	No
6.1.10a ⌿	X-Z cylinder orientation × Response	Yes	Yes
6.1.10b	X-Y×Y-Z cylinder orientation × Response	Yes	Yes
6.1.11 ⌿	Delay × X-Y cylinder orientation × Response	App	App
6.1.12	Delay × Y-Z cylinder orientation × Response	No	Yes
6.1.13 ⌿	Delay × X-Z cylinder orientation × Response	No	No

Main Effects [6.1.1 ⌿]

There was no significant main effect of Y-Z cylinder orientation in either RTs [F (1, 18) = 3.157, $p > 0.05$] or mistakes [F (1, 18) = 0.840, $p > 0.1$]. Mean RTs were 490 ms (SE = 12) for cylinders oriented downwards in the Y-Z plane and 492 ms (SE = 12) for cylinders oriented upwards in the Y-Z plane. Mean mistakes were 3.9 % (SE = 0.6) for cylinders oriented downwards in the Y-Z plane and 4.2 % (SE = 0.6) for cylinders oriented upwards in the Y-Z plane. This suggested that overall, the absolute physical proximity of a cylinder to the viewer's hands did not influence response performance.

Two-Way Interactions [6.1.8 ✓]

There was a significant interaction between X-Y cylinder orientation and hand of response in RTs [F (1, 18) = 6.990, $p < 0.05$] but not in mistakes [F (1, 18) = 1.159, $p > 0.1$] (see Figure 6.2).

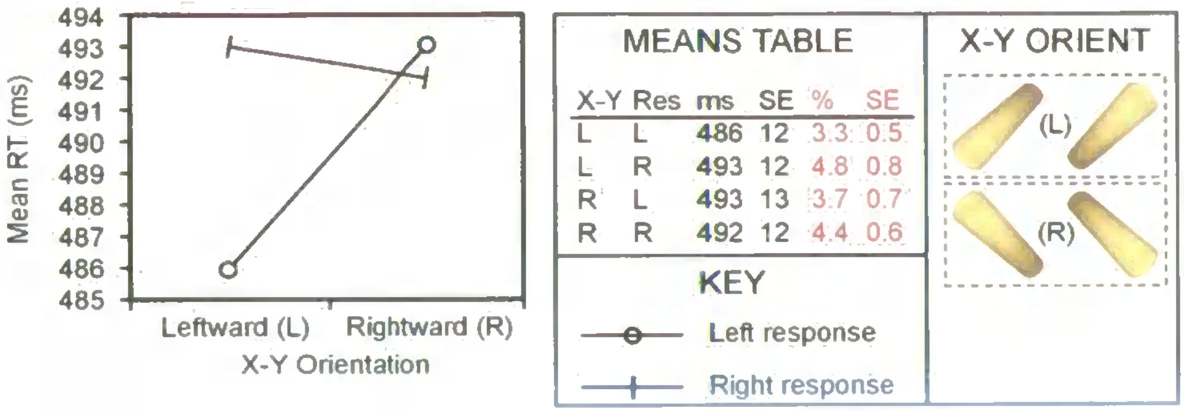


Figure 6.2 Mean mistakes as a function of X-Y cylinder orientation and hand of response

For <u>left hand responses</u>, mean RTs were 7 ms faster for cylinders oriented leftwards rather than rightwards in the X-Y plane. For <u>right hand responses</u>, mean RTs were 1 ms faster for cylinders oriented rightwards rather than leftwards in the X-Y plane. This small compatibility effect (that was most apparent for left hand responses) defied the trend in RTs thus far; a trend that has consistently shown that the X-Y orientation of a 2D line (Experiments 4.1-4.3) or a 3D cylinder (Experiments 5.1-5.3) does not have performance-related benefits associated with spatial responses (but see result [6.1.11 ✓] for a possible explanation).

Two-Way Interactions [6.1.9 ✓]

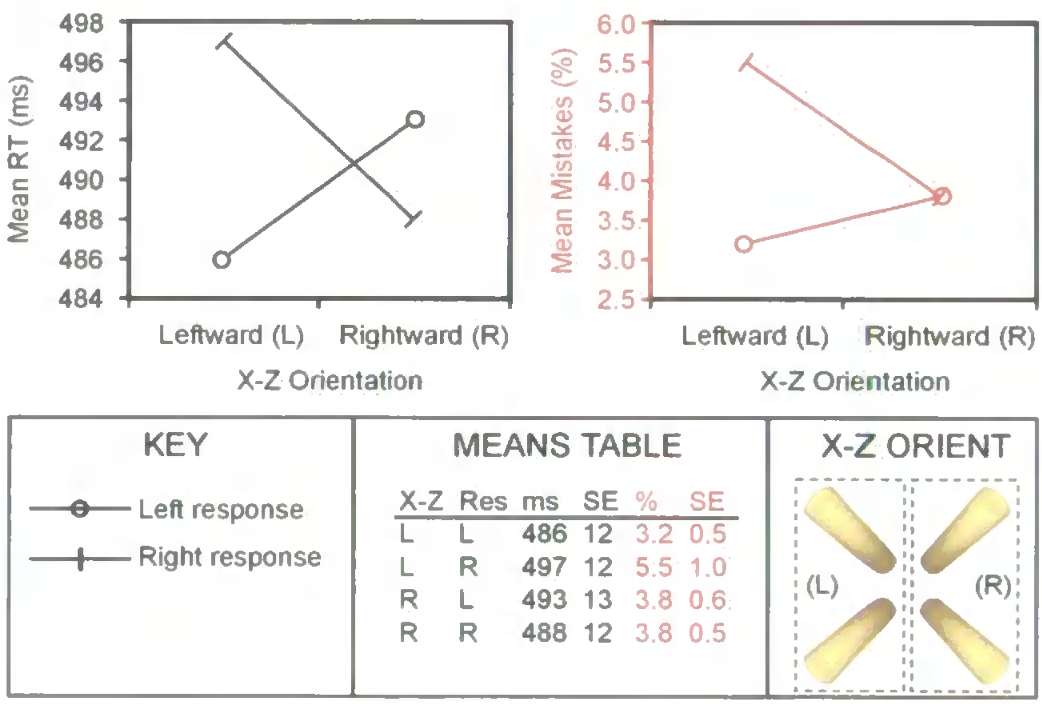
There was no significant interaction between Y-Z cylinder orientation and hand of response in RTs [F (1, 18) = 0.120, $p > 0.5$] or mistakes [F (1, 18) = 0.761, $p > 0.1$]. This suggested (in accordance with Experiments 5.1-5.3) that the Y-Z orientation of a 3D cylinder did not have any performance-related benefits associated with spatial responses. See Table 6.3 for associated means.

Table 6.3 Mean RTs (ms), mistakes (%) and standard errors (SE) for result [5.1.4 ✓]

Y-Z	Res	ms	SE	%	SE
D	L	488	12	3.2	0.6
D	R	491	12	4.6	0.8
U	L	491	13	3.8	0.5
U	R	493	12	4.6	0.7

Two-Way Interactions [6.1.10a ✓]

There was a significant interaction between X-Z cylinder orientation and hand of response in both RTs [F (1, 18) = 52.785, $p < 0.001$] and mistakes [F (1, 18) = 5.115, $p < 0.05$] (see Figure 6.3). For left hand responses, mean RTs were 7 ms faster (and mean mistakes were 0.6 % fewer) for cylinders oriented leftwards rather than rightwards in the X-Z plane. For right hand responses, mean RTs were 9 ms faster (and mean mistakes were 1.7 % fewer) for cylinders oriented rightwards rather than leftwards in the X-Z plane. This compatibility effect again suggested that the X-Z orientation of a 3-D cylinder has performance benefits associated with spatial power grip responses. This influence of X-Z orientation on responses can be seen more specifically (in terms of each global cylinder orientation), by examining the equivalent interaction (see Appendix 2, result [6.1.10b]) between Y-Z, X-Z orientation and hand of response.



X-Z	Res	ms	SE	%	SE
L	L	486	12	3.2	0.5
L	R	497	12	5.5	1.0
R	L	493	13	3.8	0.6
R	R	488	12	3.8	0.5

Figure 6.3 Mean RTs (black) and mean mistakes (red) as a function of X-Z cylinder orientation and hand of response

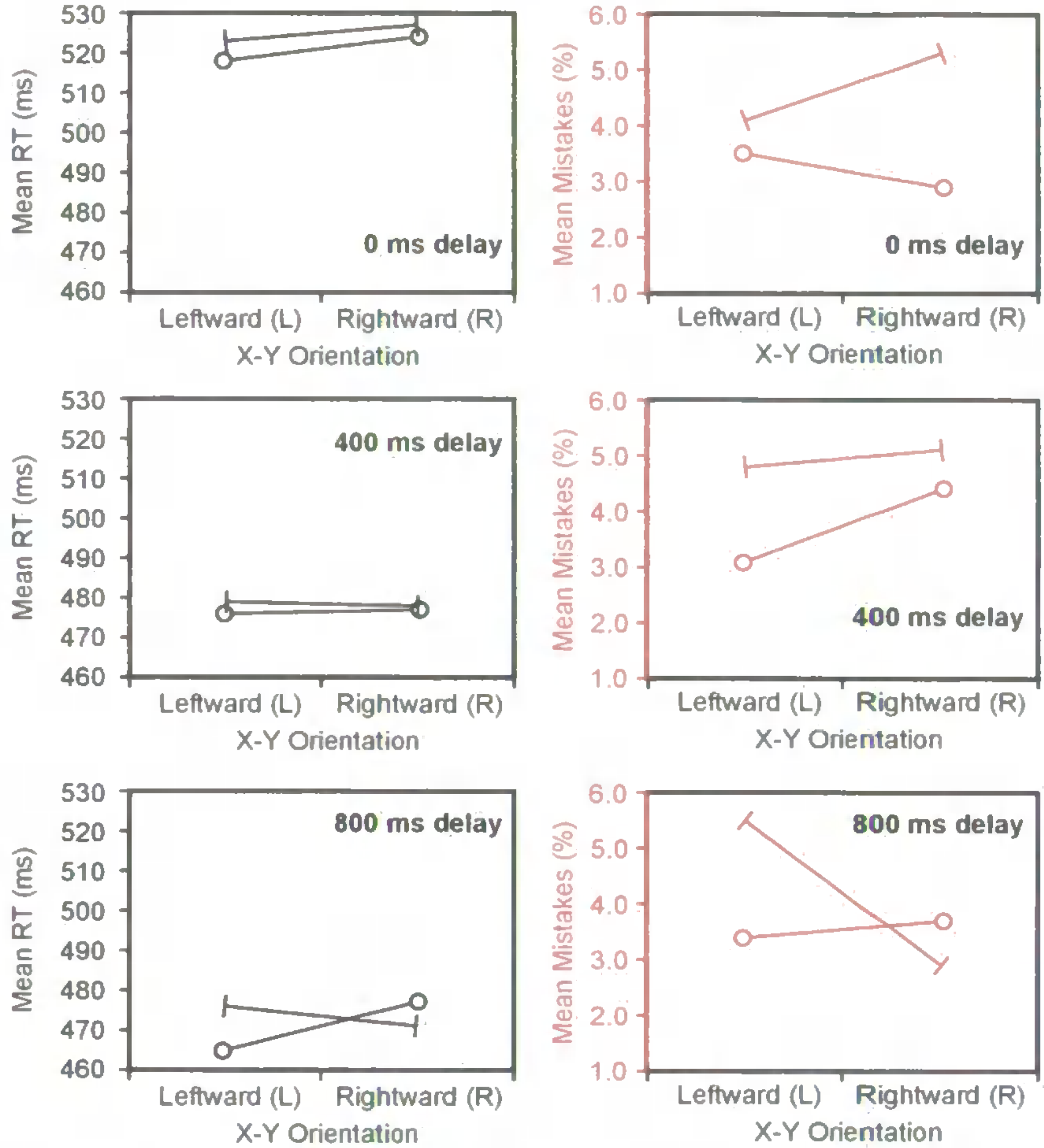
Three-Way Interactions [6.1.11✓]

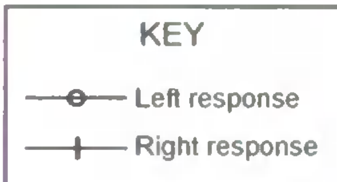
A likely explanation of the X-Y orientation × hand of response interaction reported earlier for RTs [6.1.8✓] lies in the impact of the delays. There was an interaction between delay, X-Y cylinder orientation and hand of response that approached significance in RTs [F (1, 18) = 3.005, p = 0.062] and in mistakes [F (1, 18) = 1.916, p = 0.072] (see Figure 6.4).

At delays of 0 ms (comparable to Experiments 5.1-5.3 where no significant interaction between X-Y cylinder orientation and hand of response was found), the following pattern was observed: For left hand responses, mean RTs were 6 ms faster for cylinders oriented leftwards rather than rightwards in the X-Y plane. For right hand responses, mean RTs were 4 ms faster cylinders oriented leftwards rather than rightwards in the X-Y plane. This does not appear to be an interaction. At delays of 400 ms, the following pattern was observed: For left hand responses, mean RTs were 1 ms faster for cylinders oriented leftwards rather than rightwards in the X-Y plane. For right hand responses, mean RTs were 1 ms faster for cylinders oriented rightwards rather than leftwards in the X-Y plane. This was a very small compatibility effect indeed. However, at delays of 800 ms, the following pattern was observed: For left hand responses, mean RTs were 12 ms faster for cylinders oriented leftwards rather than rightwards in the X-Y plane. For right hand responses, mean RTs were 5 ms faster for cylinders oriented rightwards rather than leftwards in the X-Y plane. This resembled a more pronounced compatibility effect. A visual comparison of the three delay conditions in the RT plots of Figure 6.4 supports the description presented above, such that the X-Y cylinder orientation appears to predominantly interact with the hand of response at delays of 800 ms.

Although further from statistical significance, the pattern of mean mistakes supported this trend at delays of 800 ms. For left responses, mean mistakes were 0.3 % fewer for leftwards rather than rightwards X-Y oriented cylinders; and for right responses, mean mistakes were 2.6 % fewer for rightwards rather than leftwards X-Y oriented cylinders.

Interestingly, at 0 ms there was a negative compatibility effect that has been seen before in result [5.1.3✗] of Experiment 5.1 (where there was similarly no delay involved).





MEANS TABLE

Del	X-Y	Res	ms	SE	%	SE
0	L	L	518	12	3.5	0.7
0	L	R	523	11	4.1	0.8
0	R	L	524	12	2.9	0.9
0	R	R	527	12	5.3	1.0
400	L	L	476	12	3.1	0.8
400	L	R	479	12	4.8	0.9
400	R	L	477	12	4.4	1.0
400	R	R	478	12	5.1	1.1
800	L	L	465	13	3.4	0.5
800	L	R	476	13	5.5	1.2
800	R	L	477	14	3.7	0.8
800	R	R	471	13	2.9	0.7

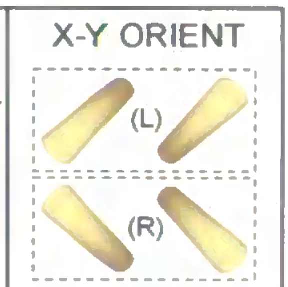


Figure 6.4 Mean mistakes as a function of delay, X-Y cylinder orientation and hand of response

Three-Way Interactions [6.1.13✓]

There was no significant interaction between delay, X-Z cylinder orientation and hand of response in either RTs [$F(1, 36) = 0.363, p > 0.5$] or mistakes [$F(1, 36) = 0.655, p > 0.5$]. This suggested that performance-related benefits associated with the X-Z orientation of a cylinder did not behave differently at SOA delay presentations of 0 ms, 400 ms or 800 ms. See Table 6.4 for associated means.

Table 6.4 Mean RTs (ms), mistakes (%) and standard errors (SE) for result [6.1.13✓]

Del	X-Z	Res	ms	SE	%	SE
0	L	L	517	12	2.9	0.7
0	L	R	528	12	5.3	1.1
0	R	L	525	13	3.5	0.5
0	R	R	522	12	4.1	0.7
400	L	L	475	13	3.3	0.7
400	L	R	486	13	6.2	1.4
400	R	L	479	12	4.2	1.0
400	R	R	471	12	3.7	0.7
800	L	L	467	13	3.3	0.6
800	L	R	477	12	4.9	1.1
800	R	L	475	14	3.8	0.9
800	R	R	470	14	3.5	0.8

6.2.3 Discussion

Experiment 6.1 revealed some familiar results. In keeping with Experiments 5.1 & 5.2 there was no significant main effect of Y-Z cylinder orientation [6.1.1✓]; and in keeping with Experiments 5.1-5.3 there was no significant interaction between Y-Z cylinder orientation and spatial response [6.1.9✓], whereas there was a significant interaction between X-Z cylinder orientation and spatial response [6.1.10a✓].

However, a significant interaction between X-Y cylinder orientation and spatial response in RTs [6.1.8✓] was not a familiar result. Indeed, *none* of the experiments that have explored the relationship between orientation in the X-Y plane and spatial response (e.g. Experiments 4.1-4.3 and 5.1-5.3) have revealed such an interaction. This interaction resembled a straightforward compatibility effect, whereby left responses were faster for cylinders oriented leftwards rather than rightwards in the X-Y plane, and vice-versa for right responses. Result [6.1.11✓] suggested that the basis for this effect in RTs resided in the SOA manipulations. Here, the interaction between X-Y cylinder orientation and hand of response only featured under the longest SOA of 800 ms. This suggested that orientation in the X-Y plane could only exert an influence on compatible responses if there was sufficient time to process that plane. In this respect, it is possible that once 'default' affordances have been automatically activated (such as might be triggered by X-Z cylinder orientation), given time, the visuomotor system 'searches' for other possibilities for action (e.g. components of actions that might be associated with the X-Y plane). Under this account, it is unlikely that the compatibility effect associated with the X-Y plane reflected the *automatic* potentiation of elements of an action.

This account receives some support from the finding that delays did not differentially affect the familiar compatibility effect obtained by the interaction between X-Z cylinder orientation and hand of response [6.1.13↯]. If this compatibility effect really did reflect a '*default* representational setting', then it might be expected that activation would occur early on and behave in a more or less consistent manner over different SOA's. Differences might nevertheless be expected when a relevance for action changes or increases (as proposed by TEC's 'feature-weighting principle'), but the use of SOA's does not necessitate *per se* a change in goal-related processes that might bring about this change.

What is not clear is how this idea of a more-or-less stable 'default' fits with published data. However, if the validity of Tucker & Ellis' (2001) time course analyses (where effect size increased linearly with viewing time) is given the benefit of the doubt, there is room for speculation regarding the current findings.

One might speculate that the visuomotor system is hungry, as it were, for action-relevant information. When size is the most action-relevant object property (by virtue of being set-up by the precision/power responses), then there is little or no further size-related information to be gleaned from, say, a small round object. Consequently, the system might build upon what it does have (i.e. it increases the weighting of a feature that codes a particular grasp-type). This increased weighting might underpin Tucker & Ellis' (2001) linear increase in effect size.

In contrast, when orientation is the most action-relevant object property (by virtue of being set-up by spatial responses), then in an object such as a cylinder (that is variously oriented in different planes), there *is* further orientation-related information to be gleaned from the cylinder. Consequently, free resources can be directed towards additional or alternative sources of spatially relevant object information. In the meantime, the system 'makes do' with what it already has (e.g. the activity of a 'default representational setting' associated with X-Z cylinder orientation remains more-or-less stable). Indeed, this additional or alternative orientation-related information that the system is uncovering might relate to the X-Y plane (a possibility that is supported by result [6.1.11 ↯] discussed earlier).

In conclusion, this experiment provided preliminary support for the Task Context Hypothesis. In changing the context of relations between cylinders and responses (in this case the temporal context was manipulated by different SOA's) a new compatibility effect was uncovered that was associated with the typically redundant X-Y orientation of a cylinder. In contrast, the reliably established compatibility effect associated with X-Z cylinder orientation, remained unchanged by the various SOA manipulations. This finding added support to the notion of a 'default representational setting' that remains more-or-less stable (at least when there is no pressure to change).

In continuing to explore the influence of task context, the next experiment changed the nature of the cylinder presentation further still. Spatial responses were still made to the surface pattern of an oriented cylinder (but SOA's were not employed), and instead of using static images the cylinders now had the appearance of moving towards the viewer.

6.3 Experiment 6.2

Another obvious manipulation of the cylinder (without changing its global orientation) was to make it appear as if it was moving in a straight line directly towards the viewer. While most S-R-C studies have used static stimuli for convenience, many investigations of perception-action compatibility effects have used dynamic events (e.g. the moving squares study by Michaels, 1998; as discussed in Chapter 1). Indeed, in reviewing such cases Hommel et al. (2001) suggested that just like static properties of a stimulus, dynamic properties of a stimulus event are also automatically coded and activate feature-overlapping responses. With this recommendation (whereby in principle, perception-action compatibility effects might equally be expected using dynamic stimulus events), this experiment questioned whether the fact that an oriented cylinder appeared to be moving might change the nature of the compatibility effects previously established in Chapter 5.

6.3.1 Method

Participants

As described for Experiment 3.1 (undergraduate volunteers etc.), but 20 participants took part.

Apparatus

As described for Experiment 3.1 (small darkened room, PC etc.), but two graspable power grip response devices (from Experiment 5.2) were used.

Materials

The stimulus set was based on the cylinders used in Experiments 5.1-6.1. However, there were the following differences that enabled the apparent motion of these cylinders. The screen background was coloured black at all times. The inter-trial stimulus was a black screen with a centrally placed progress bar, which updated as the stimuli for each trial loaded. Below the progress bar were the words "Loading Animation…Please Wait". The target stimuli were based on the four global cylinder orientations (with a wobbly and straight surface pattern version of each), but these cylinders were not set in a chequered room, but rather a black background. For each global cylinder orientation there were 15 versions (15 frames) from small (depicting a 'far away' cylinder) to large (depicting a 'close up' cylinder). When run in an animation sequence, a visual impression of motion was created (with the initially small 'far away' cylinder appearing to move towards the viewer as it increased in size).

Design

The design was the same as that described for Experiment 5.1. Thus the two dependent variables were RTs and mistakes, and the within subjects independent variables were hand of response (left, right) and a choice of two of the following: X-Y cylinder orientation (leftwards, rightwards), Y-Z cylinder orientation (upwards, downwards) or X-Z cylinder orientation (leftwards, rightwards). The between subjects independent variable was mapping rule. Thus the experiment was based on a 2 × 2 × 2 × 2 repeated measures design, as illustrated previously in Chapter 5 (see Table 5.2).

In mapping rule: condition 1 (MR: C1) [n = 10], left hand responses were made to cylinders with a wobbly surface pattern and right hand responses were made to cylinders with a straight surface pattern. The 'hand of response-cylinder pattern' pairing was reversed in mapping rule: condition 2 (MR: C2) [n = 10]. Both cylinder patterns were shown 50 times for each of the four global cylinder orientations (thus 50 presentations × 2 patterns × 4 global cylinder orientations = 400 trials). The order of cylinder pattern and global cylinder orientation was randomised in one block of 400. As responses were dependent on the pattern of the cylinder, the independent variables of cylinder orientation (X-Y, Y-Z and X-Z) were task irrelevant.

Procedure part a (general procedure)

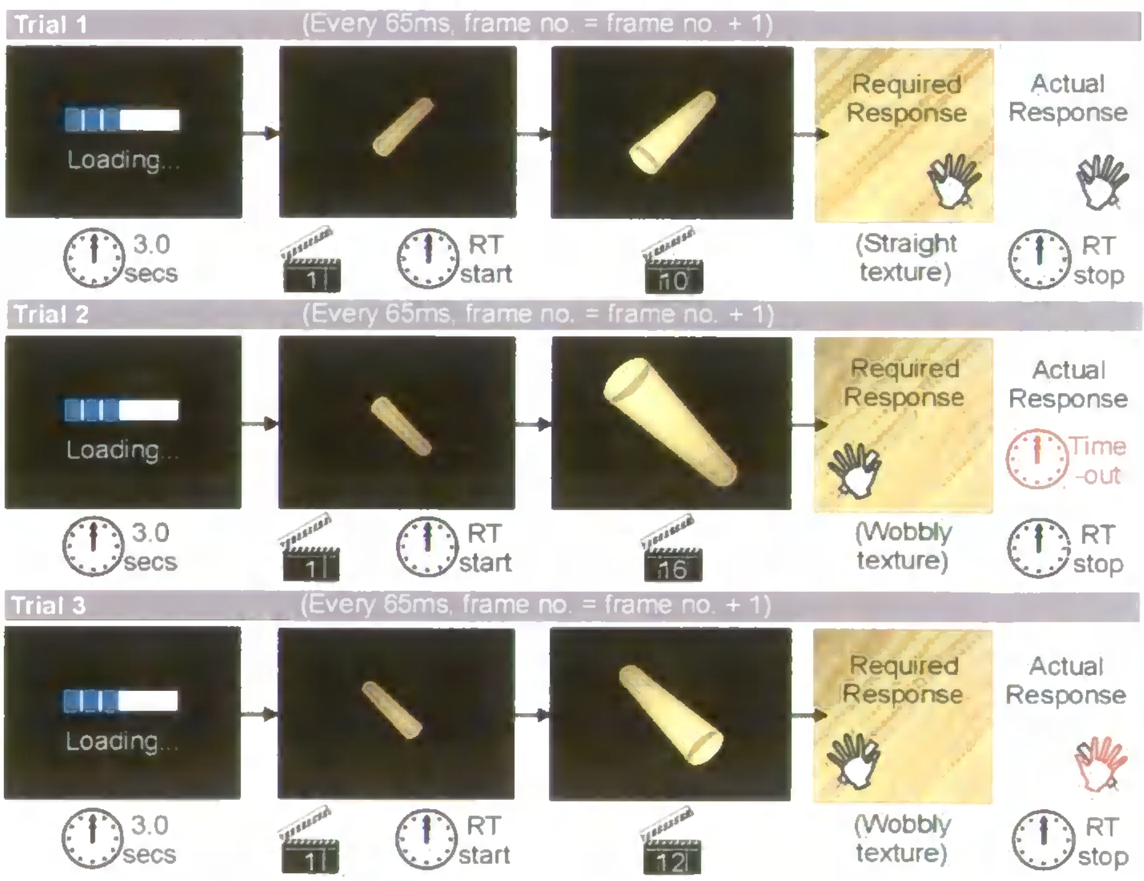
As described for Experiment 3.1 (consent forms, general instruction of fast and accurate responses etc.).

Procedure part b (trial procedure)

Participants were pseudo-randomly allocated to an experimental group (Group 1- MR: C1, Group 2- MR: C2). According to their group allocation, they were instructed which hand to respond with for the two cylinder patterns (wobbly and straight). In addition, participants were informed that they must respond while the cylinder was moving, which meant they had a window of just over a second to respond for each trial. After completing the practice session, the main experiment began. The trial procedure is outlined in Box 6.3.

Box 6.2 Trial procedure for Experiment 6.2. The clock icon depicts a millisecond timer, the clapperboard icon depicts a frame and the hand icon depicts a power grip response. The colour red corresponds to an incorrect response.

The schematic below depicts three typical trials for a participant assigned to MR: C1 (left responses for wobbly cylinder pattern, right responses for straight cylinder pattern). For each trial, the inter-trial stimulus was shown for 3 seconds (while the animation loaded) and was then replaced with the target stimulus animation. A millisecond timer measured the time that the target stimulus ran for on the screen. This could be until the participant made a left or right response, or until 1040 ms (65 ms × 16 frames) had passed and the trial was given time-out. When a response was made the animation stopped at its current frame, whereas after 1040 ms the animation had iterated through all 16 possible frames. Following the response (or time-out), the target stimulus animation was immediately replaced with the inter-trial stimulus for a new trial, thus completing the loop.



Procedure part c (feedback routine)

The feedback routine was the same as that described for Experiment 5.1 (two progress charts). There were 20 feedback blocks, each consisting of 20 trials.

6.3.2 Results

Analytical Procedure and Summary Results

Analyses were as described for Experiment 3.1 (correct and incorrect response data sets etc.), but there was only an analysis by participants. Two repeated measures ANOVAs (located in Appendix 1) were performed on the between subjects independent variable of mapping rule, and the within subjects independent variables of hand of response and two of the following: X-Y, Y-Z or X-Z cylinder orientation. Participants were entered as a random factor, and the dependent variables were RTs (the first ANOVA) and mistakes (the second ANOVA). The results for Experiment 6.2 are summarised in Table 6.5. Key results are reported in the text and remaining results are reported in Appendix 2.

Table 6.5 Main effects and interactions reported in Experiment 6.2. Key: statistical significance status (approaching, yes, no). ↗ depicts results of key theoretical interest.

Result no.	Source	Correct Responses	Incorrect Responses
6.2.1 ↗	Y-Z cylinder orientation	Yes	No
6.2.2	Response	Yes	Yes
6.2.3	X-Y cylinder orientation	No	Yes
6.2.4 ↗	X-Y cylinder orientation × Response	No	No
6.2.5 ↗	Y-Z cylinder orientation × Response	No	No
6.2.6 ↗	X-Z cylinder orientation × Response	No	No
6.2.7	Mapping Rule × X-Y cylinder orientation	No	Yes

Main Effects [6.2.1 ↗]

There was a significant main effect of Y-Z cylinder orientation in RTs [F (1, 18) = 5.846, $p < 0.05$] but not mistakes [F (1, 18) = 0.630, $p > 0.1$]. Mean RTs were 598 ms (SE = 12) for cylinders oriented downwards in the Y-Z plane and 592 ms (SE = 11) for cylinders oriented upwards in the Y-Z plane. [Mean mistakes were 5.3 % (SE = 0.9) for cylinders oriented downwards in the Y-Z plane and 4.8 % (SE = 0.8) for cylinders oriented upwards in the Y-Z plane]. Thus mean RTs were 6 ms faster for cylinders oriented upwards rather than downwards in the Y-Z plane, suggesting that when the cylinder was moving performance was improved when cylinders were oriented upwards. It is possible that this reflected an effect of the absolute physical proximity of the cylinder. However, as with the main effect of Y-Z orientation (in both RTs and mistakes) found earlier in Experiment 5.3 (see [5.3.3✗]), this pattern did not support Visual Attribute Hypothesis 4. It was predicted that cylinders oriented downwards in the Y-Z plane might be responded to faster and with fewer mistakes, owing to the closer physical proximity of an end of the cylinder to a particular hand. As was suggested earlier, an alternative possibility is that this result reflected a preference for cylinders that would require an upward reach trajectory.

Two-Way Interactions [6.2.4✗]

There was no significant interaction between X-Y cylinder orientation and hand of response in either RTs [F (1, 18) = 0.039, $p > 0.5$] or mistakes [F (1, 18) = 0.863, $p > 0.1$]. This suggested (in accordance with the previous findings of Experiments 5.1-5.3) that the X-Y orientation of a 3D cylinder (that on this occasion appeared to be moving) did not have any performance-related benefits associated with power grip responses. See Table 6.6 for associated means.

Table 6.6 Mean RTs (ms), mistakes (%) and standard errors (SE) for result [6.2.4✗]

X-Y	Res	ms	SE	%	SE
L	L	580	11	3.8	1.0
L	R	607	13	4.9	1.0
R	L	582	11	4.5	0.6
R	R	610	12	7.1	1.2

Two-Way Interactions [6.2.5✗]

There was no significant interaction between Y-Z cylinder orientation and hand of response in RTs [F (1, 18) = 0.579, $p > 0.1$] or mistakes [F (1, 18) = 0.153, $p > 0.5$]. This suggested (in accordance with the previous findings of Experiments 5.1-5.3 and 6.1) that the Y-Z orientation of a 3D cylinder did not have any performance-related benefits associated with spatial responses. See Table 6.7 for associated means.

Table 6.7 Mean RTs (ms), mistakes (%) and standard errors (SE) for result [6.2.5✓]

Y-Z	Res	ms	SE	%	SE
D	L	583	11	4.3	0.8
D	R	613	13	6.3	1.2
U	L	580	12	4.0	0.8
U	R	604	12	5.7	1.0

Two-Way Interactions [6.2.6✓]

There was no significant interaction between X-Z cylinder orientation and hand of response in either RTs [$F\ (1, 18) = 1.004$, $p > 0.1$] or mistakes [$F\ (1, 18) = 0.115$, $p > 0.5$]. In stark contrast to the consistent findings of Experiments 5.1-6.1, this finding suggested that the apparent motion of the cylinders had wiped out any performance-related benefits normally associated with their X-Z orientation. See Table 6.8 for associated means.

Table 6.8 Mean RTs (ms), mistakes (%) and standard errors (SE) for result [6.2.6✓]

X-Z	Res	ms	SE	%	SE
L	L	583	12	4.1	1.0
L	R	608	13	5.8	1.1
R	L	579	11	4.2	0.7
R	R	609	12	6.3	1.0

6.3.3 Discussion

This Experiment has also provided some familiar results. In keeping with Experiment 5.3 (but unlike Experiments 5.1, 5.2 & 6.1) there was a significant main effect of Y-Z cylinder orientation [6.2.1✓]. Again, this finding showed an advantage in RTs (but this time not in mistakes) for those cylinders that were physically *farther* overall to a particular hand (that is, cylinders oriented upwards). It is possible that this reflected a preference for object orientations that would require an upward rather than downward reach trajectory.

In keeping with Experiments 5.1-5.3 there was no significant interaction between X-Y cylinder orientation and spatial response [6.2.4✓], and in keeping with Experiments 5.1-6.1 there was no significant interaction between Y-Z cylinder orientation and spatial response [6.2.5✓]

Of most interest was the finding that this experiment has bucked the trend established by four previous experiments. There was no significant interaction between X-Z cylinder orientation and hand of response [6.2.6✓]. Given the previous reliability of this interaction, the finding that it has disappeared is striking. At a guess, one might have expected that a moving cylinder would *increase* the significance for action that is normally associated with orientation in the X-Z plane. In providing only a small window of opportunity during which to respond, a moving cylinder might have promoted a state of heightened awareness- a pressure to act that would make the detection of affordances all the more important. This did not appear to be the case however. Instead, any performance-related benefits associated with the X-Z plane were completely eradicated (or perhaps overridden) within the behavioural context of apparent motion.

In hindsight it is possible that in preparing to catch a moving cylinder (assuming that is what participants were doing), rather than affording an interceptive reach and grasp with a particular hand, a cylinder moving directly towards the viewer instead afforded the withdrawal of a particular hand (much as in catching a cricket ball, the catching hand moves in the same direction as the travelling ball in order to take the pace off it). Even if there was no automatic preparation for catching, the moving cylinder may still have evoked a withdrawal response by a particular hand (Fischer, pers. comm.): a phenomenon that is commonly found in cases of 'visual looming' (e.g. where a head instinctively draws back to avoid a looming stimulus).

In conclusion, whatever the underlying cause may have been, this result is of particular interest because it demonstrates that under certain circumstances (i.e. when apparent motion occurs in the direction of the viewer), a previously established 'default representational setting' (associated with orientation in the X-Z plane) can be overridden or eradicated. This finding was in accord with the Task Context Hypothesis.

The final experiment continued to apply a more dynamic feel to the stimuli by making an oriented cylinder a mere component in a functional lever-like device. The task demanded that participants moved this lever up or down (with visual feedback of this event) according to some arbitrary response-contingent rule. In doing this, the same Task Context Hypothesis was tested, namely whether or not the context of a task would promote the modulation, overriding or elaboration of otherwise default representational settings.

6.4 Experiment 6.3

The manipulations of cylinders in the previous two experiments have focussed on their viewer-independent context (the surface pattern of the cylinder changed at various temporal intervals, or the cylinder itself appeared to be moving). This experiment however, also investigated the viewer-dependent context of a cylinder. Here, an oriented cylinder was merely a component in a functioning lever-like device. When participants made a left or right key press response, the cylinder component of this lever-like device rotated around its pivoting bar in an upward or downward direction. In actively involving participants in this way (such that their responses effected a change in the lever), it was expected that in accordance with the Task Context Hypothesis, the nature of the compatibility effects associated with a cylinder component might change given its new context as part of a functioning lever. Furthermore it was expected that new compatibility effects might arise as a result of the new action-relevant contingencies.

A further consideration that related to the use of a functionally unambiguous lever[47] was the possibility that participants might be sensitive to movement difficulty or awkwardness, *were* they to physically (rather than virtually) move the lever (i.e. if they employed motor imagery that simulated real physical movements). Johnson and colleagues have recently investigated the extent to which motor imagery is related to real motor processes (e.g. Johnson, 1998, 2000a, 2000b; Johnson, Corballis & Gazzaniga, 2001). In a series of studies by Johnson (2000a), participant's sensitivity to reach and grasp comfort and awkwardness was investigated using real and imagined reaches to a wooden dowel that could be variously oriented about 360° in the picture plane (i.e. the X-Y plane).

[47] In the cylinder experiments, cylinders were functionally ambiguous because one might choose to grasp a cylinder at either end. However with a cylinder that was a mere component of a lever (it was pierced at one end by a metal bar around which it could pivot), this cylinder component became functionally unambiguous-in order to use the lever, one could only realistically grasp near the free end of the cylinder component.

This dowel, (half of which was coloured pink and the other half tan), was suspended by an axle in the centre of a black wooden box. Invisible to the participants, the rear of the axle protruded through the back wall of the box, and a pointer that was fixed to this axle indicated to the experimenter the angle of the dowel orientation (degrees were mapped on the back of the box). The box was open at the front to allow a hand to reach in and grasp the dowel. As a general rule of interaction that applied to all experiments, the dowel was to be grasped (or in some cases, imagined to be grasped) in a power grip with the 'thumbside' of the hand on the pink end of the dowel (or sometimes the tan end). In this sense the dowels were functionally unambiguous, since participants were always instructed which coloured end to grasp.

In the first experiment, limits of comfortable hand rotation were explored. At the beginning of each trial the experimenter moved the dowel into a vertical position with the pink end facing upwards. In a prospective judgement condition (PJ) participants were instructed to estimate how far the dowel could rotate before it would become uncomfortable for a particular hand. At the beginning of a trial the participant was instructed which hand to base their decision on. The experimenter then rotated the dowel clockwise or anticlockwise at a rate of approximately 30°/s. When participants estimated that the rotation was no longer comfortable, they said "stop", and the experimenter recorded the angle of the dowel. In a motor control (MC) condition, a similar method was employed, but participants themselves rotated the dowel clockwise or anticlockwise with a particular hand until it became uncomfortable. The results showed no statistical difference between the two conditions. Thus estimated limits of comfortable hand supination and pronation were highly consistent with values obtained from actual hand rotations[48].

In following experiments that used equivalent methodologies (although PJ conditions now used graphically rendered images of the variously oriented dowel), judgements regarding

[48] While it is interesting that orientation in the X-Y plane influenced judgements and responses (whereas in Chapter 5 of this thesis orientation in the X-Y plane consistently failed to exert an influence on responses), it should be noted that a coloured end of the dowel gave action-related significance to that end of the dowel.

the awkwardness involved in adopting a prescribed grip (overhand with the right hand) were consistent across imagined and actual grips. Furthermore, selection of the most natural grip (overhand versus underhand) or the most natural hand (left or right) consistently reflected the least awkward choice, for both PJ and MC conditions. PJ's (made verbally as fast as possible) involving awkward hand postures had longer RTs and were less accurate. Similarly RTs for both grip and hand judgements increased as a function of the angular distance between the current positions of participants hands (thus relating to the extent of the would-be-movement), and the orientation of the chosen posture (thus relating to the awkwardness of the posture). It was concluded that making PJs involved motor imagery or mentally simulating actions (processes that might be closely related to somatomotor processes); and that remarkably, these simulations were highly sensitive to rather sophisticated considerations of comfort or awkwardness (based on various biomechanical parameters).

As has been argued previously in Chapter 2, mental simulation, emulation or imagery are intimately related to real visuomotor processes. Given the complex nature of the stimuli and task used in this lever experiment, one might predict that participants would be sensitive to this complexity *from an action perspective*. That is, in deciding whether a lever must move up or down according to some rule (which the task required in order to select a response) participants might have been sensitive to the physical difficulty or awkwardness of moving a lever, *were* they to physically (rather than virtually) move it. More specifically, in deciding whether a lever must move up or down, processes of motor imagery may become involved that are similar to those involved when physically interacting with a real lever.

Indeed the nature of the lever configurations used meant that some were intrinsically easy to move up or down, whereas others would require especially awkward or difficult movements. Aside from several notable differences in this experiment when compared to Johnson's (2000a) series of studies (such as the use of a functioning lever rather than a dowel, and the use of dynamic visual feedback triggered by a remote key press), it is of special significance to note that in Johnson's studies the comfort of a movement was made *explicit* (either in judgement or actual grasping). For example, in the MC condition of one experiment participants were instructed to grasp a particular end of the dowel (the pink or tan end depending upon instruction) with the most 'natural' hand (i.e. least awkward hand). In the PJ condition they were instructed to say "left" or "right" for the most natural hand, *were* they to grasp a particular end of the dowel (the pink or tan end depending upon instruction). Thus a preferred hand was chosen with *explicit* reference to how comfortable it was (or would be).

The current lever experiment however, had no such explicit reference. The left and right hand key presses were used to produce an upward or downward movement of the lever, and it was an arbitrary rule (the length of a previously presented line) that helped determine which movement should be made. In fact no reference was made to potentially moving the lever with the hands (let alone any reference to movement difficulties). For all intents and purposes, the only thing participants were explicitly concerned with was whether a lever should move up or down. For them, it was incidental that a left or right hand key press produced this movement. Crucially then, any suggestion in the data (reflected by latency of responses or frequency of mistakes) that participants were sensitive to the physical difficulty of moving a particular lever, would implicate automatic, (explicitly) goal-independent processes of the sort championed by the APH.

6.4.1 Method

Participants

As described for Experiment 3.1 (undergraduate volunteers etc.), but 20 participants took part.

Apparatus

Keys 'a' and 'l' on the keyboard (that was placed directly in front of the monitor) served as response keys for the left and right hands respectively.

Materials (inter-trial stimulus set)

A background 'room' derived from the one described in Experiment 5.1 served as the inter-trial stimulus. It differed with respect to its pattern however, in that it was not chequered, but uniformly grey. There were two versions of this stimulus. In each version there was a vertical white line that was centrally placed and superimposed over the room. In one version the line was short (about ¼ the height of the room), and in the other version the line was long (about ¾ the height of the room). Consequently the inter-trial stimulus set consisted of two images (a room with a short line, and a room with a long line).

Materials (target stimulus set)

The target stimulus set was based on the global cylinder orientations described in Experiment 5.1. However there were some important differences. Firstly, the background 'room' was grey and not chequered, and shadows cast by the object set in the room were shown. Secondly, the cylinder was always a neutral pattern (not straight or wobbly). Thirdly, there were two versions of each of the four global cylinder orientations. In one version a metallic bar pierced the end of the cylinder that was nearest to the viewer (see Figure 6.5), and in the other version a metallic bar pierced the end of the cylinder that was farthest from the viewer (see Figure 6.6). In each case, the bar was fixed to the left and right walls of the room, thus supporting the cylinder in space to create the impression of a lever-like device. Consequently the target stimulus set) consisted of eight levers (four global cylinder orientations × two bar positions).

A definition of each of the eight lever configurations can be seen in Table 6.9. These definitions are based on the orientation of the cylinder component within each of the three planes and the position of the bar in two planes (X-Y – high or low, and X-Z – near or far).

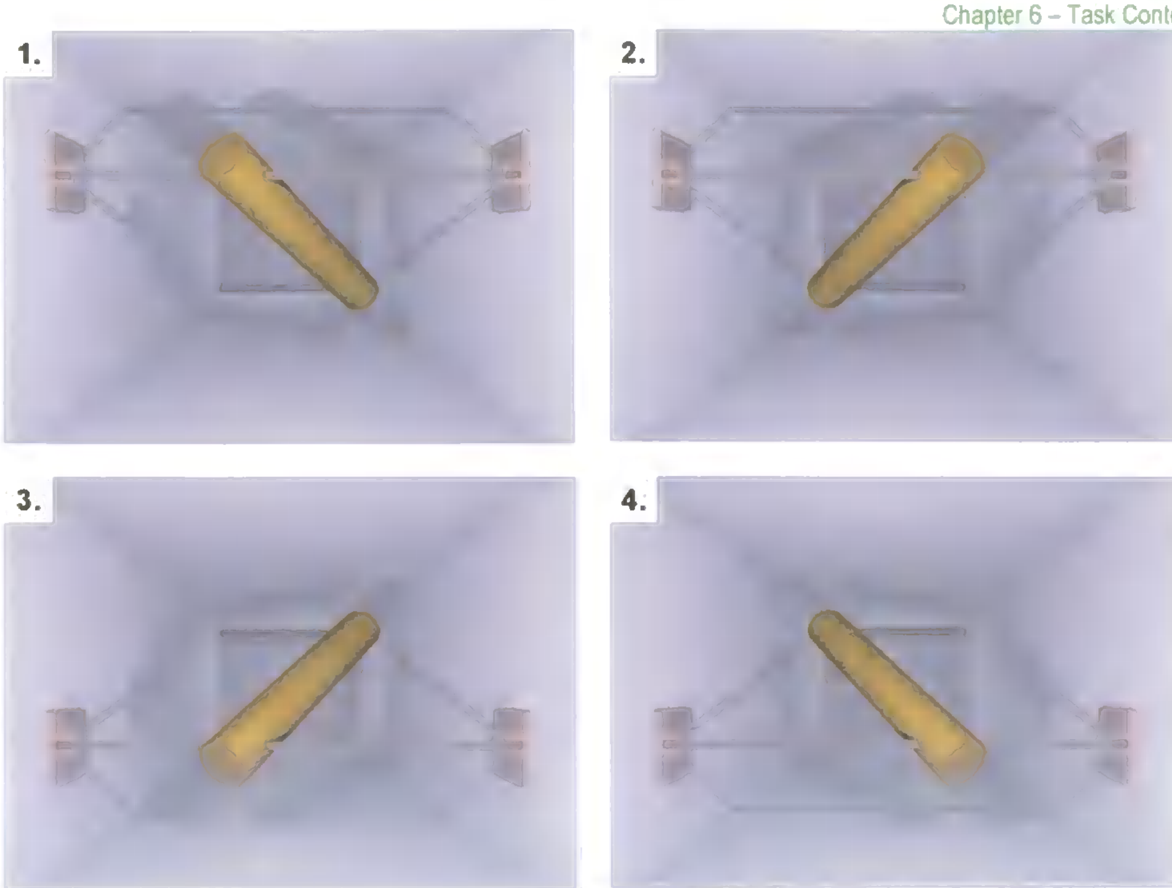


Figure 6.5 Levers 1-4 consisting of the four global orientations of cylinders that are pierced by a near bar

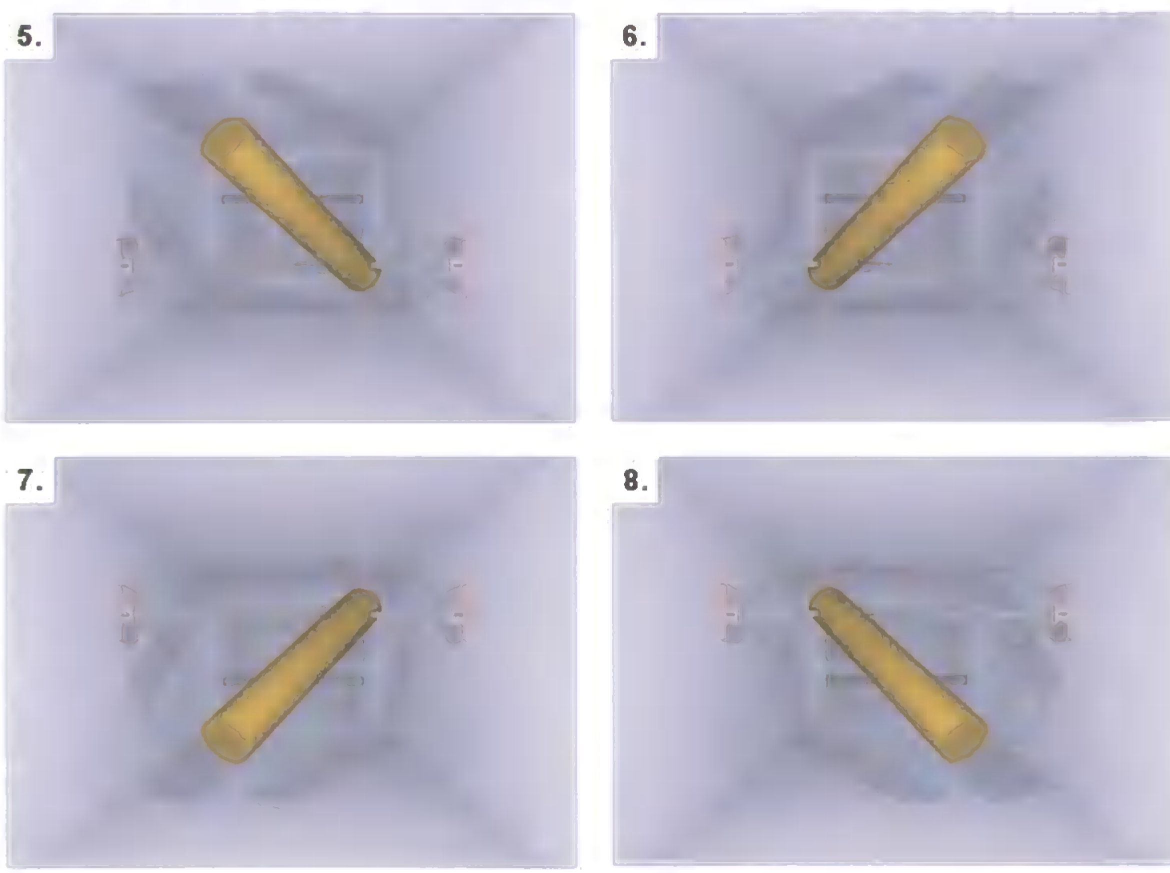
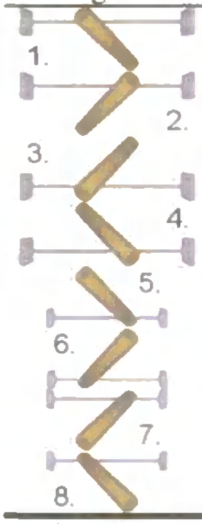


Figure 6.6 Levers 5-8 consisting of the four global orientations of cylinders that are pierced by a far bar

Table 6.9 A definition of each lever configuration in terms of its dimension-specific orientations and bar positions.



Lever Configuration	Dimension-Specific Orientation
1.	X-Y (Rightwards); Y-Z (Upwards); X-Z (Leftwards); Bar (High); Bar (Near)
2.	X-Y (Leftwards); Y-Z (Upwards); X-Z (Rightwards); Bar (High); Bar (Near)
3.	X-Y (Leftwards); Y-Z (Downwards); X-Z (Leftwards); Bar (Low); Bar (Near)
4.	X-Y (Rightwards); Y-Z Downwards); X-Z (Rightwards); Bar (Low); Bar (Near)
5.	X-Y (Rightwards); Y-Z (Upwards); X-Z (Leftwards); Bar (Low); Bar (Far)
6.	X-Y (Leftwards); Y-Z (Upwards); X-Z (Rightwards); Bar (Low); Bar (Far)
7.	X-Y (Leftwards); Y-Z (Downwards); X-Z (Leftwards); Bar (High); Bar (Far)
8.	X-Y (Rightwards); Y-Z Downwards); X-Z (Rightwards); Bar (High); Bar (Far)

Materials (feedback stimulus set)

For each of the eight levers, there were two possible feedback images depicting the lever in an end-state position, as if it had been moved either up to the ceiling of the room, or down to the floor of the room. With relation to its start position (i.e. the target stimulus set) the end-state position of a given lever reflected the result of either a short movement or a long movement. End-state levers that reflected a *short* movement from the start positions of levers 1-4 (see Fig. Figure 6.5 above) are presented in Figure 6.7. End-state levers that reflected a *short* movement from the start positions of levers 5-8 (see Figure 6.6 above) are presented in Figure 6.8. End-state levers that reflected a *long* movement from the start positions of levers 1-4 (see Figure 6.5 above) are presented in Figure 6.9. End-state levers that reflected a *long* movement from the start positions of levers 5-8 (see Figure 6.6 above) are presented in Figure 6.10. Consequently the feedback stimulus set consisted of sixteen lever configurations (four global orientations × two bar positions × two end-state cylinder positions).

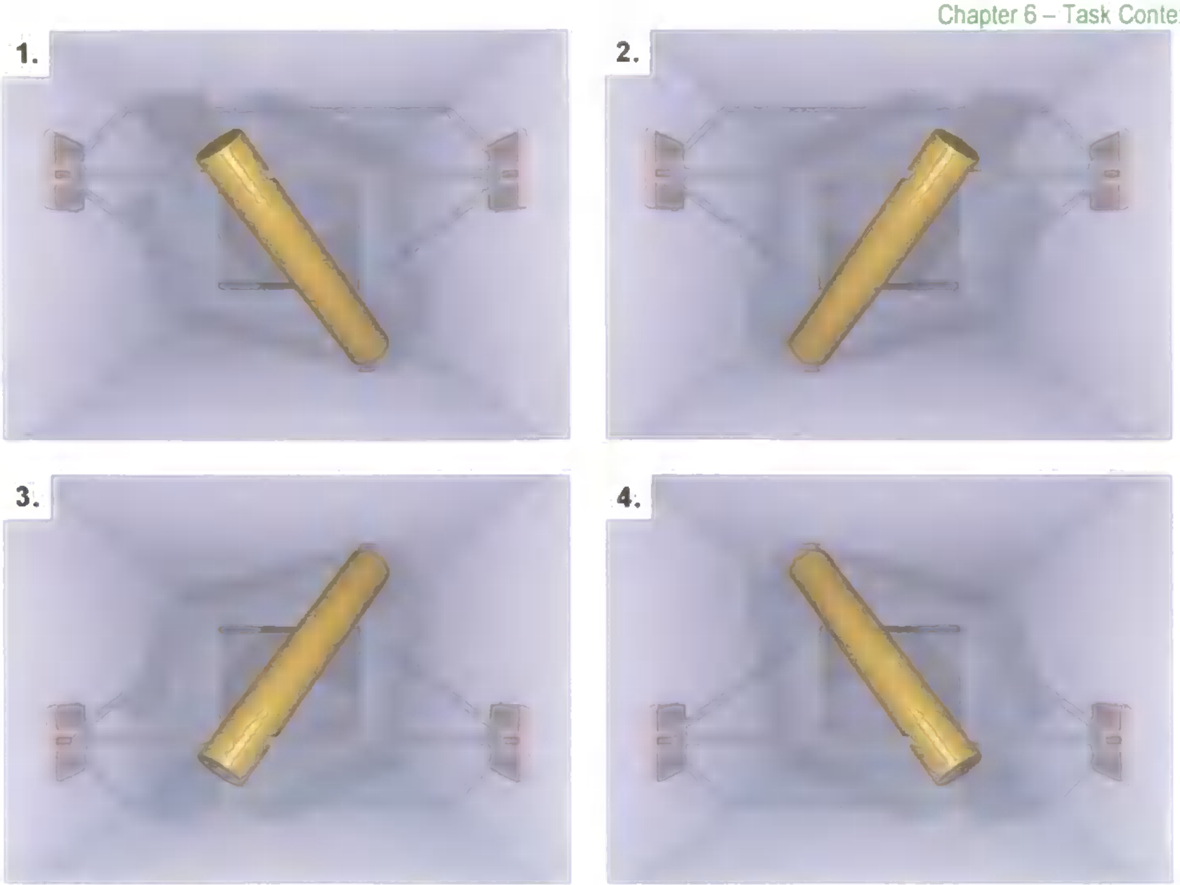


Figure 6.7 End-state positions that have resulted from a short movement of levers 1-4

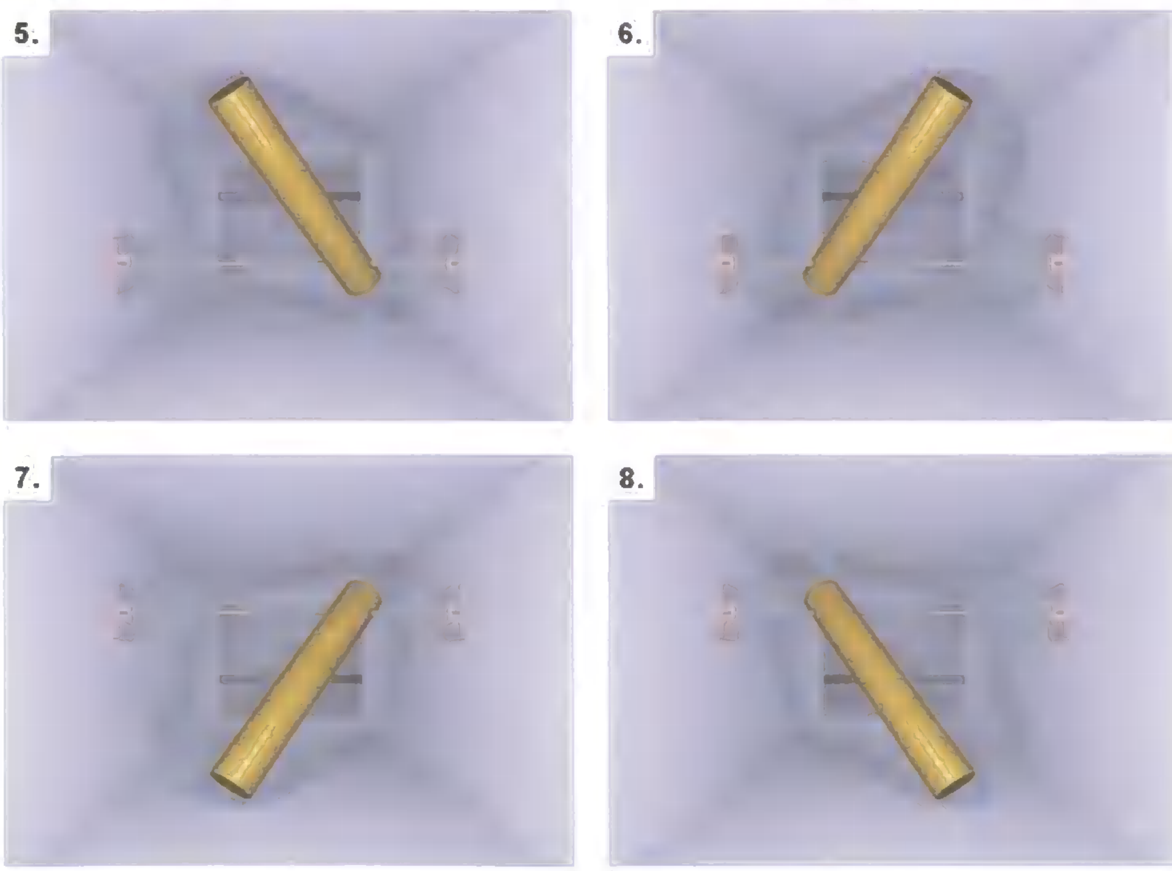


Figure 6.8 End-state positions that have resulted from a short movement of levers 5-8

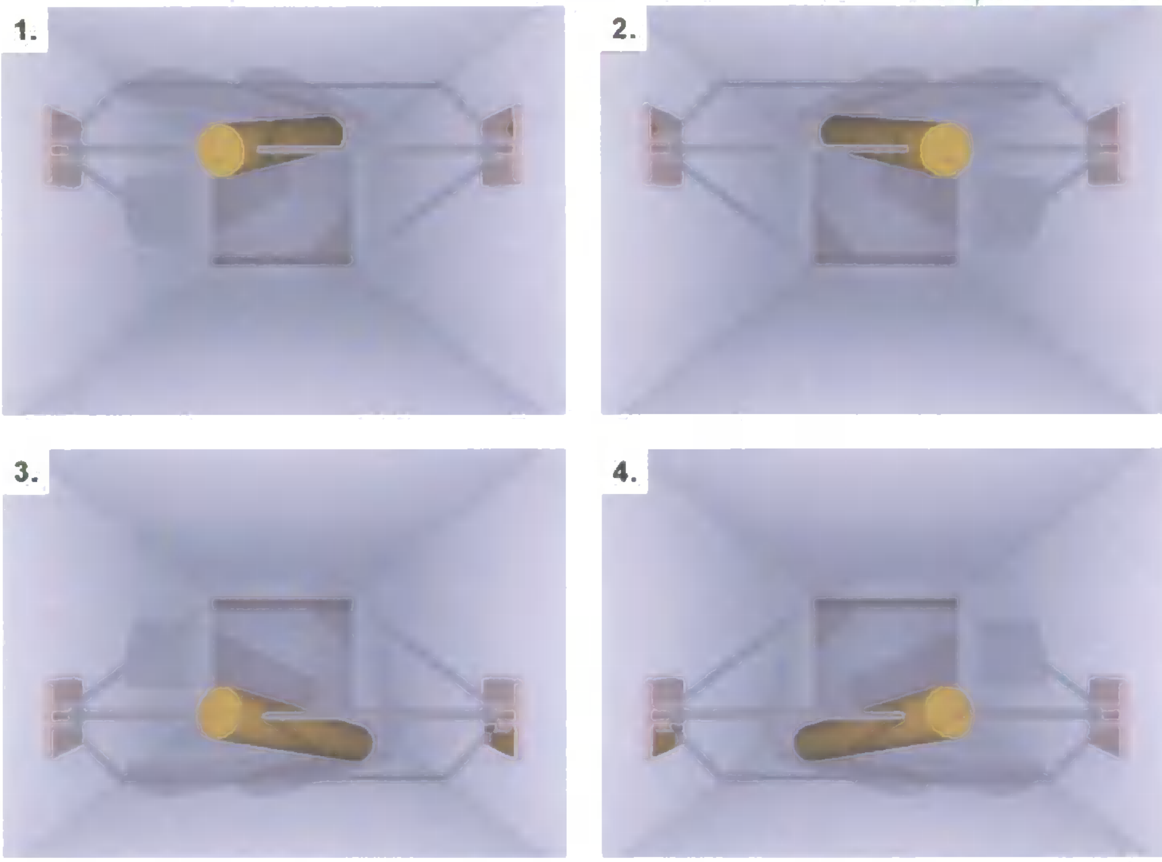


Figure 6.9 End-state positions that have resulted from a long movement of levers 1-4

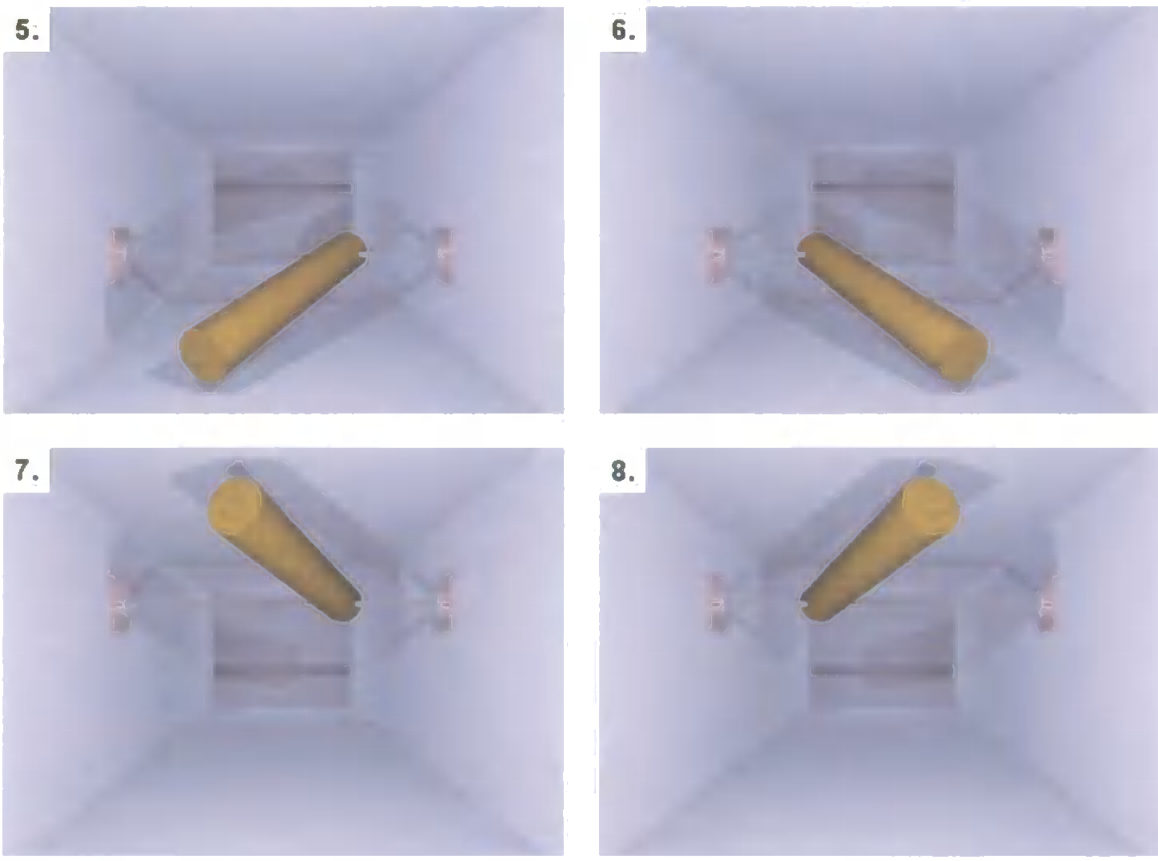


Figure 6.10 End-state positions that have resulted from a long movement of levers 5-8

Design

The two dependent variables were RTs and mistakes. The within subjects independent variables were hand of response (left, right); a choice of two of the following: X-Y cylinder orientation (leftwards, rightwards), Y-Z cylinder orientation (upwards, downwards) or X-Z cylinder orientation (leftwards, rightwards); and a choice of one of the following[49]: X-Y bar position (high, low) or X-Z bar position (near, far). The between subjects independent variable was mapping rule. In mapping rule: condition 1 (MR: C1) [n = 10], left hand responses were made to move the lever upwards towards the ceiling and right hand responses were made to move the lever downwards towards the floor. The 'hand of response-lever movement pairing' was reversed in mapping rule: condition 2 (MR: C2) [n = 10]. Thus the experiment was a 2 × 2 × 2 × 2 × 2 repeated measures design (see Table 6.10).

Table 6.10 Experimental design for Experiment 6.3. Key: mapping rule (MR), condition 1 (C1), condition 2 (C2), experimental group (G)

		MR	
		C1	C2
Hand of Response	Left	G_1 (n = 10)	G_2 (n = 10)
	Right	G_1 (n = 10)	G_2 (n = 10)
X-Y cylinder orientation	Leftwards	G_1 (n = 10)	G_2 (n = 10)
	Rightwards	G_1 (n = 10)	G_2 (n = 10)
Y-Z cylinder orientation	Upwards	G_1 (n = 10)	G_2 (n = 10)
	Downwards	G_1 (n = 10)	G_2 (n = 10)
X-Z cylinder orientation	Leftwards	G_1 (n = 10)	G_2 (n = 10)
	Rightwards	G_1 (n = 10)	G_2 (n = 10)
X-Y bar position	High	G_1 (n = 10)	G_2 (n = 10)
	Low	G_1 (n = 10)	G_2 (n = 10)
X-Z bar position	Near	G_1 (n = 10)	G_2 (n = 10)
	Far	G_1 (n = 10)	G_2 (n = 10)

[49] Just as the cylinder orientation in a particular plane (e.g. X-Z plane) is *necessarily* specified by the interaction of cylinder orientations in the other two planes (e.g. X-Y × Y-Z planes); the bar position in a particular plane (X-Z plane) is *necessarily* specified by the interaction between the cylinder orientation in any two planes and the bar position in the remaining plane (e.g. X-Y × Y-Z cylinder orientations × X-Y bar position). For example, a cylinder oriented leftwards in the X-Y plane, downwards in the Y-Z plane, and pierced by a bar that is positioned high in the X-Y plane; *must*, as a consequence, be oriented leftwards in the X-Z plane and pierced by a bar that is positioned far in the X-Z plane. Therefore, just as only two planes are required to account for cylinder orientation, it is also the case that only one plane needs to be entered as a variable in the design to account for bar position.

A practice session consisted of two blocks of 24 trials (one block with all levers attached to a near bar, and the other block with all levers attached to a far bar). The main experiment consisted of 480 trials, divided into 20 blocks of 24 trials. Inter-trial stimulus presentations: In each block, each vertical line (long and short) was randomly presented 12 times (thus 12 presentations × 2 lines × 20 blocks = 480 trials). Target stimulus presentations: The X-Z position of the metallic bar (near or far) changed alternately between blocks; hence for each trial in any block of 24 trials the position of the metallic bar remained constant (thus, [10 blocks × 24 trials × 1 bar position] + [10 blocks × 24 trials × 1 bar position] = 480 trials). Within each block of 24 trials all four global cylinder orientations were randomly presented 6 times (thus 6 presentations × 4 global cylinder orientations × 20 blocks = 480 trials). Feedback stimulus design: In each trial, when a left or right response was made that specified an upward or downward movement of the lever, the corresponding end-state lever configuration was presented (creating the visual impression of movement).

Procedure part a (general procedure)

As described for Experiment 3.1 (consent forms, general instruction of fast and accurate responses etc.).

Procedure part b (trial procedure)

Participants were pseudo-randomly allocated to an experimental group (Group 1- MR: C1, Group 2- MR: C2). According to their group allocation, they were instructed which hand to respond with (left or right) in order to effect a particular lever movement (upward or downward). Participants were shown a small real-life model of the lever to assist in explaining its simple mechanics- in particular how the cylinder component could pivot around the bar that pierced it. They then watched the experimenter perform the computer task for approximately five minutes. While performing the task, the experimenter gave a verbal commentary of the thought processes employed to complete each trial. Following a practice session (48 trials), participants began the main experiment.

The experimental trial procedure is outlined in Box 6.5.

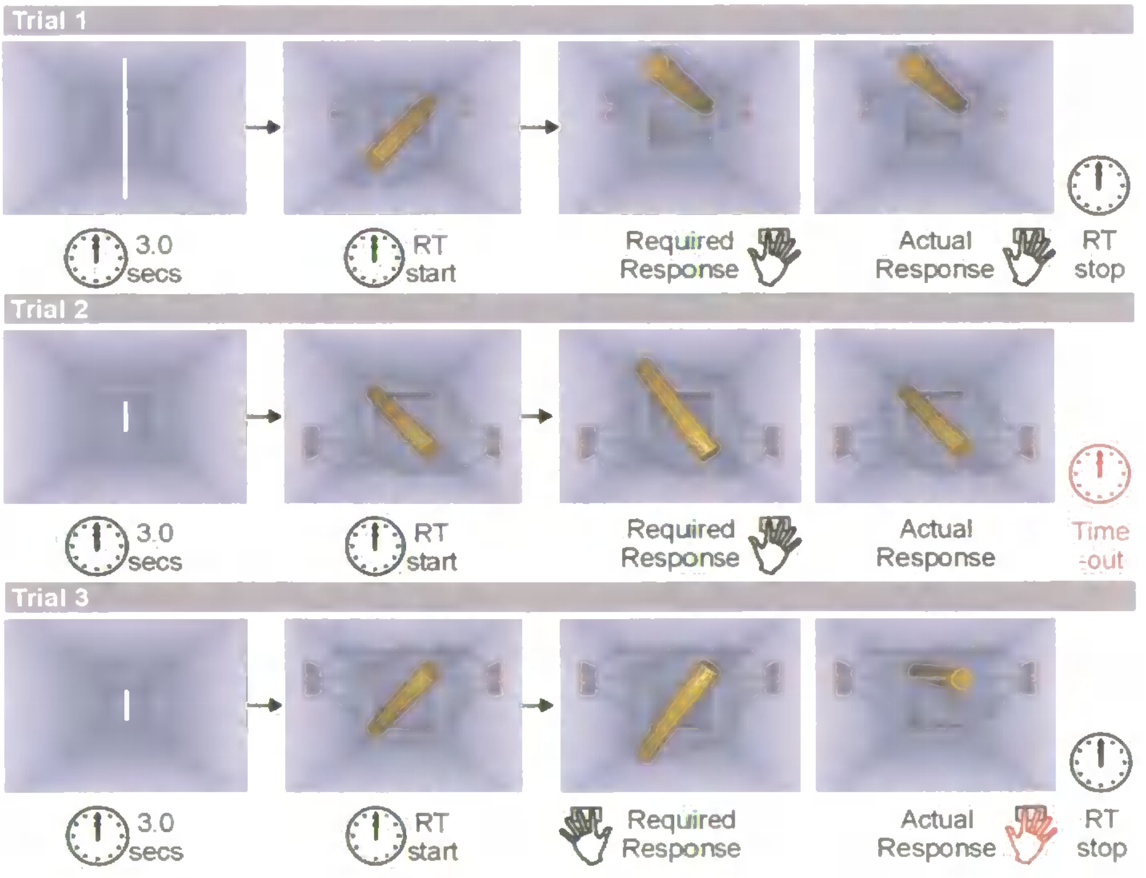
Box 6.3 Trial procedure for Experiment 6.6. The clock icon depicts a millisecond timer, and the hand icon depicts a key press response. The colour red corresponds to an incorrect response.

The schematic below depicts three typical trials for a participant assigned to MR: C2 (left responses to move the lever downwards, right responses to move the lever upwards).

Inter-trial stimulus procedure: For each trial, the inter-trial stimulus was shown for 3.0 seconds. When the inter-trial stimulus appeared (a short or long vertical white line), participants assessed whether the line was short or long. A short line corresponded to the shortest distance the lever needed to move in order to make contact with either the floor or the ceiling of the room. A long line corresponded to the longest distance the lever needed to move in order to make contact with either the floor or the ceiling of the room.

Target stimulus procedure: The inter-trial stimulus was then replaced with an initial lever configuration. Participants had to move the lever (by pressing a left or right key) in the direction (upwards or downwards) that would achieve the movement distance previously specified by the inter-trial stimulus line. Perhaps the easiest way to do this was to visualise the lever moving up or down. All participants were advised to employ this strategy. If no response was made, after three seconds had passed the trial was given time-out.

Feedback stimulus procedure: If a response was made, the initial lever configuration was replaced by the end-state lever configuration that had been specified by the response. The perception of this was of the lever pivoting around its bar in an upwards or downwards direction. If the end-state lever configuration violated the requirements specified by the inter-trial line length (e.g. the lever had moved a long rather than short distance), then a beep sounded to indicate that a mistake had been made. After 1.5 seconds (or time-out), the feedback stimulus was immediately replaced with the inter-trial stimulus for a new trial, thus completing the loop.



Procedure part c (feedback routine)

The experimental feedback routine was the same as that described for Experiment 5.1 (two progress charts). There were 20 feedback blocks, each consisting of 24 trials.

6.4.2 Results

Analytical Procedure and Summary Results

Analyses were as described for Experiment 3.1 (correct and incorrect response data sets etc.), but there was only an analysis by participants. Two repeated measures ANOVAs (located in Appendix 1) were performed on the between subjects independent variable of mapping rule, and the within subjects independent variables of hand of response; two of the following: X-Y, Y-Z or X-Z cylinder orientation; and one of the following: X-Y or X-Z bar position. Participants were entered as a random factor, and the dependent variables were RTs (the first ANOVA) and mistakes (the second ANOVA). The results for Experiment 6.3 are summarised in Table 6.11. Key results are reported in the text and remaining results are reported in Appendix 2.

Table 6.11 Main effects and interactions reported in Experiment 6.3. Key: statistical significance status (approaching, yes, no). ✓ depicts results of key theoretical interest.

Result no.	Source	Correct Resp.	Incorrect Resp.
6.3.1 ✓	X-Z bar position	Yes	No
6.3.2	Response	Yes	Yes
6.3.3 ✓	Mapping Rule	App	No
6.3.4a ✓	X-Z bar position ×Y-Z cylinder orientation	App	No
6.3.4b	X-Z bar position × X-Y×X-Z cylinder orientation	App	No
6.3.5a	X-Z bar position × X-Y cylinder orientation × mapping rule	Yes	No
6.3.5b	X-Z bar position × Y-Z ×X-Z cylinder orientation × mapping rule	Yes	No
6.3.6a	X-Z bar position × X-Z cylinder orientation × mapping rule	Yes	Yes
6.3.6b	X-Z bar position × X-Y × Y-Z cylinder orientation × mapping rule	Yes	Yes
6.3.7a	X-Y cylinder orientation × hand of response × mapping rule	App	No
6.3.7b	Y-Z × X-Z cylinder orientation × hand of response × mapping rule	App	No
6.3.8a	X-Z cylinder orientation × hand of response × mapping rule	No	Yes
6.3.8b	X-Y × Y-Z cylinder orientation × hand of response × mapping rule	No	Yes
6.3.9a ✓	X-Z bar position × X-Z cylinder orientation × hand of response	Yes	Yes
6.3.9a	X-Z bar position × X-Y × X-Z cylinder orientation × hand of response	Yes	Yes
6.3.10a ✓	X-Z bar position × Y-Z cylinder orientation × hand of response × mapping rule	Yes	Yes
6.3.10b	X-Z bar position × X-Y × X-Z cylinder orientation × hand of response × mapping rule	Yes	Yes

Main Effects [6.3.1 ✓]

There was a significant main effect of X-Z bar position in RTs [F (1, 18) = 37.983, $p <$ 0.001] but not in mistakes [F (1, 18) = 1.956, $p > 0.1$]. Mean RTs were 23 ms faster when the bar position was in the background (far bar: 511 ms, SE = 10.3) rather than in the foreground (near bar: 534 ms, SE = 8.8). This effect can be interpreted in terms of possibilities for action. When the position of the bar was far, it would not restrict possible reaches to the cylinder component (hence fast RTs). When the position of the bar was near, it could restrict possible reaches towards and possible movements of the cylinder component once grasped (hence slower RTs).

Main Effects [6.3.3 ✓]

There was a main effect of mapping rule that approached significance in RTs [F (1, 18) = 4.193, $p = 0.055$] but not in mistakes [F (1, 18) = 0.016, $p > 0.5$]. Mean RTs were 39 ms faster for participants in MR: C1 (left responses move lever upwards, right responses move lever downwards) rather than MR: C2 (right responses move lever upwards, left responses move lever downwards). Mean RTs were 503 ms (SE = 13.3) for participants in MR: C1, and 542 ms (SE = 13.3) for participants in MR: C2. This might simply reflect one group of participants having faster reactions than another group, or it might reflect an advantage for moving levers upwards with the left hand and downwards with the right hand.

Two-Way Interactions [6.3.4a ✓]

There was an interaction that approached significance between X-Z bar position and Y-Z cylinder orientation in RTs [F (1, 18) = 4.093, $p = 0.058$] (see Figure 6.11) but not in mistakes [F (1, 18) = 0.378, $p > 0.5$]. The main effect of bar position is apparent in this interaction (levers with far bars were responded to faster than levers with near bars). When the bar position was far, mean RTs were 9 ms faster when the cylinder component was oriented upwards rather than downwards in the Y-Z plane. When the bar position was near, mean RTs were 9 ms faster when the cylinder component was oriented downwards rather than upwards in the Y-Z plane.

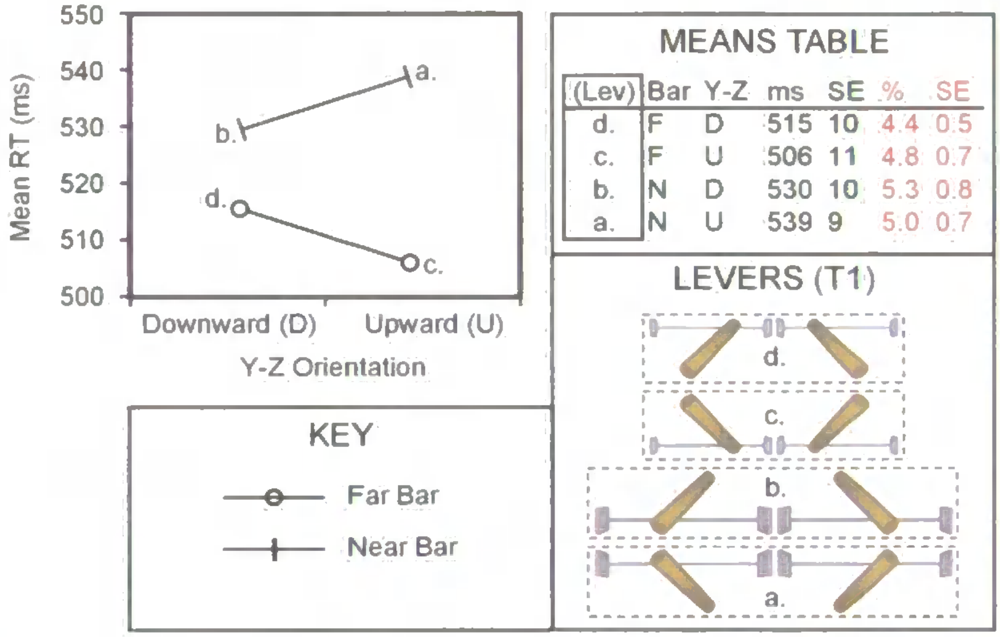


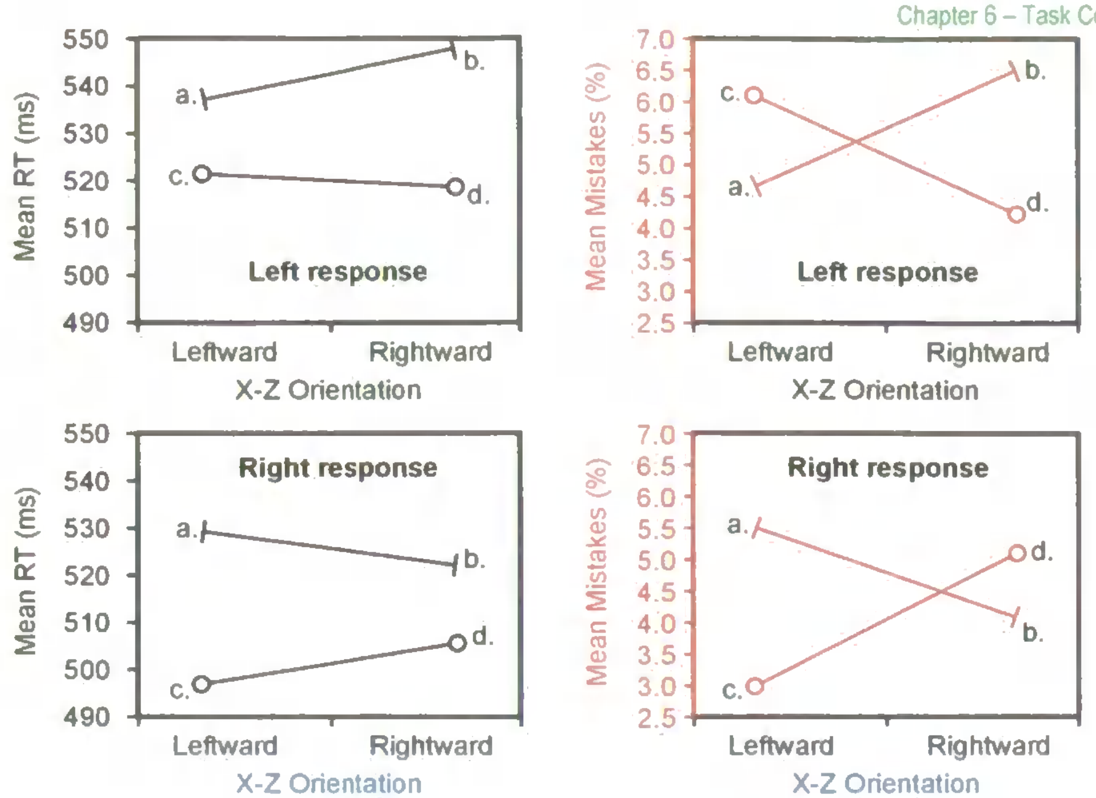
Figure 6.11 Mean RTs as a function of X-Z bar position and Y-Z cylinder orientation

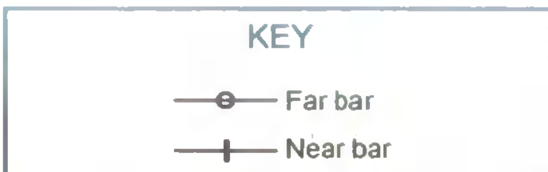
By referring to the lever configurations depicted in Figure 6.11, it can be seen that in terms of action (i.e. potential interactions with the free end of the cylinder component), regardless of the bar position there was an advantage for lever configurations that would require an upward (b and c) rather than downward reach trajectory (a and d). This is discussed in section 6.4.3.

From this perspective it can be seen how each specific cylinder component was responded to (but not each lever, since X-Z bar position does not feature in this interaction).

Three-Way Interactions [6.3.9a ✓]

There was a significant interaction between X-Z bar position, X-Z cylinder orientation and hand of response in RTs [F (1, 18) = 12.570, $p < 0.005$] and in mistakes [F (1, 18) = 15.060, $p < 0.005$] (see Figure 6.12).





MEANS TABLE

(Lev)	Bar	X-Z	Res	ms	SE	%	SE
c	F	L	L	522	12	6.1	0.9
c	F	L	R	497	10	3.0	0.6
d	F	R	L	519	11	4.3	0.7
d	F	R	R	506	11	5.1	0.7
a	N	L	L	538	10	4.7	0.9
a	N	L	R	529	9	5.5	0.9
b	N	R	L	548	10	6.5	0.7
b	N	R	R	522	9	4.1	0.7

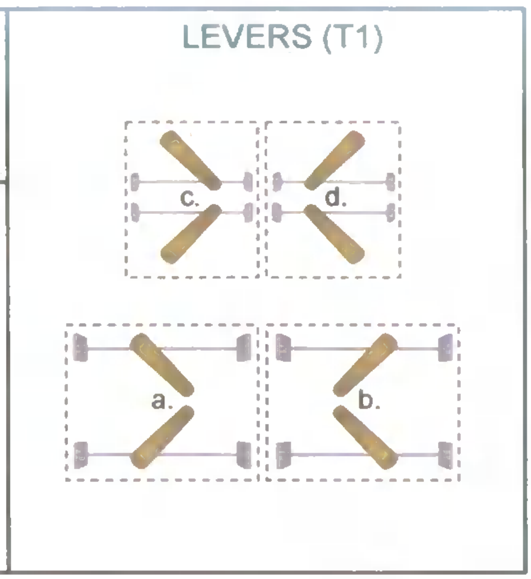


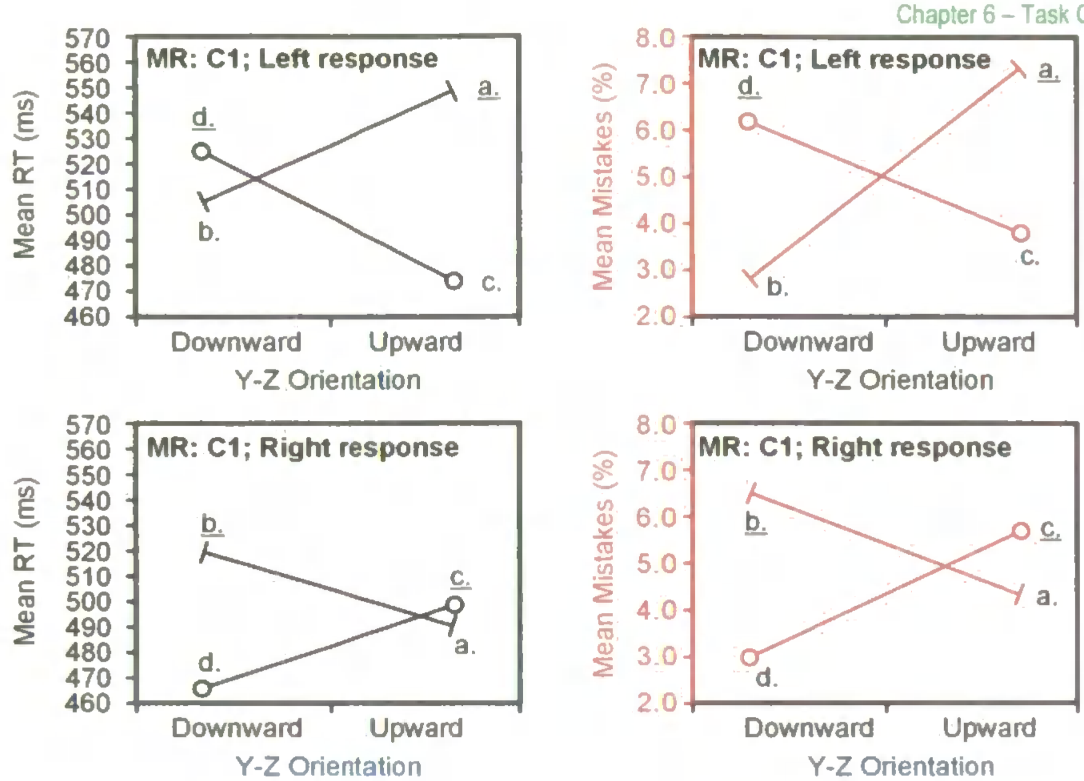
Figure 6.12 Mean RTs (black) and mean mistakes (red) as a function of X-Z bar position, X-Z cylinder orientation and hand of response

The main effect of hand of response is apparent in this interaction (right responses were responded to faster than left responses). When the bar position was far the following pattern was observed: For left hand responses, mean RTs were 3 ms faster (and mistakes 1.8 % fewer) for cylinders oriented rightwards rather than leftwards in the X-Z plane. For right hand responses, mean RTs were 9 ms faster (and mistakes 2.1 % fewer) for cylinders oriented leftwards rather than rightwards in the X-Z plane. When the bar position was near the following pattern was observed: For left hand responses, mean RTs were 11 ms faster (and mistakes 1.8 % fewer) for cylinders oriented leftwards rather than rightwards in the X-Z plane. For right hand responses, mean RTs were 7 ms faster (and mistakes 1.4 % fewer) for cylinders oriented rightwards rather than leftwards in the X-Z plane.

From the observed trend reported above, it can be seen that there was an advantage for a particular lever configuration when the hand of response was the same hand that would be needed to make a contralateral reach-to-grasp movement towards the free end of the cylinder component. It will be noted that this is the reverse of the usual X-Z compatibility effect found in previous experiments, which demonstrated with respect to stand-alone cylinders (rather than components of a lever), an advantage for a 'default' ipsilateral compatibility (e.g. left hand compatibility with a cylinder oriented leftwards in the X-Z plane).

Higher Order Interactions [6.3.10a ✓]

There was a significant interaction between mapping rule, bar position, Y-Z cylinder orientation and hand of response in RTs [F (1, 18) = 17.683, $p < 0.005$] and in mistakes [F (1, 18) = 47.234, $p < 0.001$] (see Figures 6.13 and 6.14).



KEY

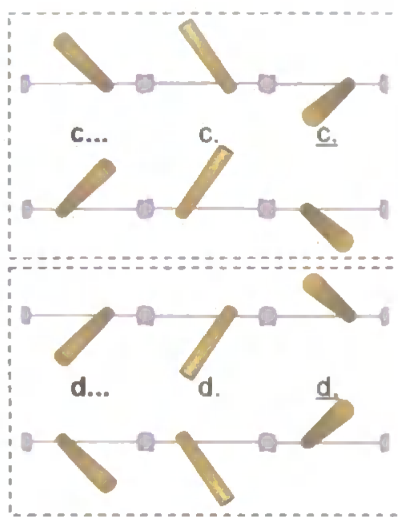
—o— Far bar

—+— Near bar

MEANS TABLE

(Lev)	MR	Bar	Y-Z	Res	ms	SE	%	SE
d	C1	F	D	L	524	18	6.2	0.8
d	C1	F	D	R	466	13	3.0	1.1
c	C1	F	U	L	474	16	3.8	1.5
c	C1	F	U	R	498	18	5.7	0.9
b	C1	N	D	L	505	14	2.8	1.3
b	C1	N	D	R	520	19	6.5	1.2
a	C1	N	U	L	548	17	7.3	1.2
a	C1	N	U	R	490	12	4.3	1.1

LEVERS (T1- T2)



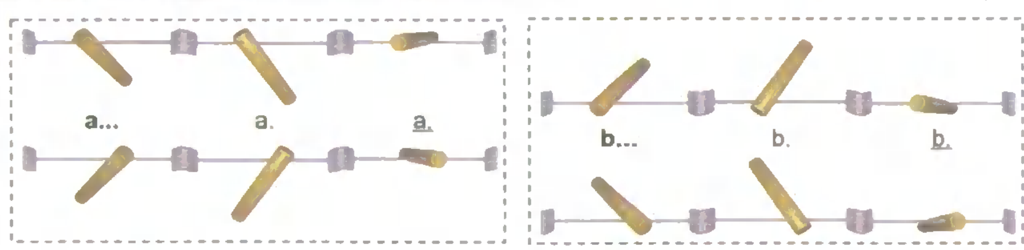
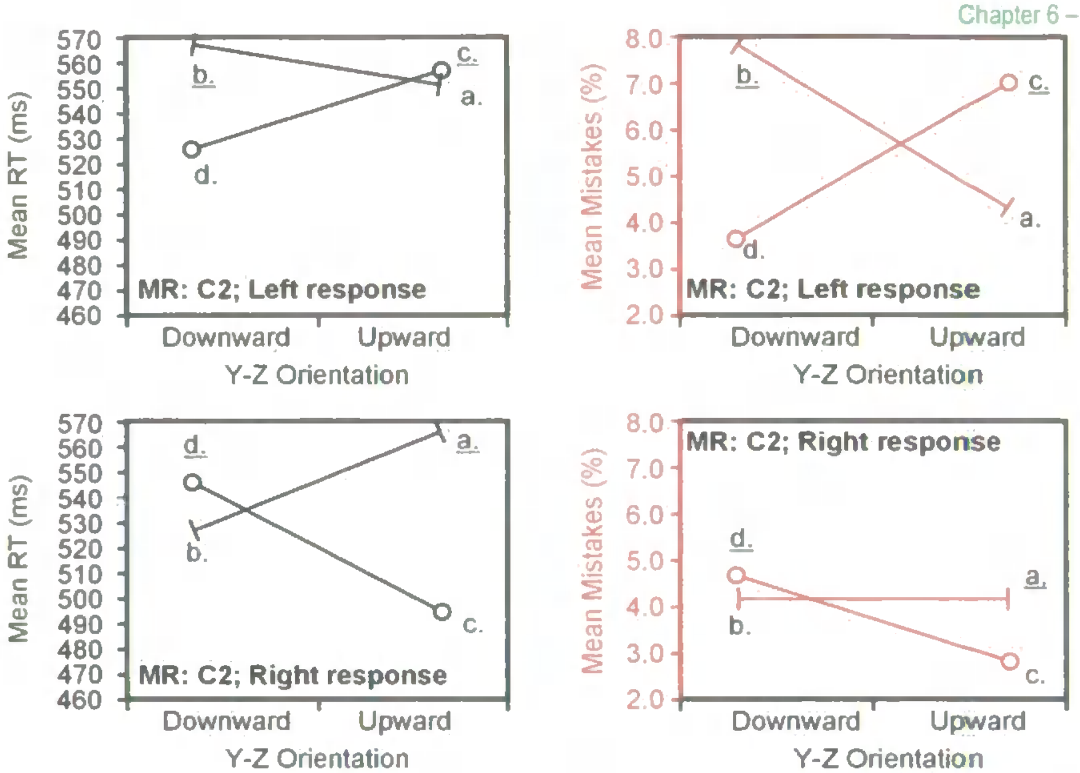


Figure 6.13 Mean RTs (black) and mean mistakes (red) as a function of X-Z bar position, Y-Z cylinder orientation, hand of response and mapping rule (n.b. MR: C1 in this figure)



KEY

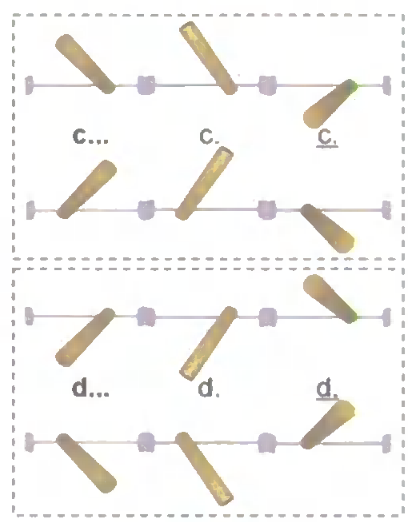
Far bar

Near bar

MEANS TABLE

(Lev)	MR	Bar	Y-Z	Res	ms	SE	%	SE
d	C2	F	D	L	526	18	3.7	0.8
d̲	C2	F	D	R	546	13	4.7	1.1
c̲	C2	F	U	L	557	16	7.0	1.5
c	C2	F	U	R	495	18	2.8	0.9
b̲	C2	N	D	L	567	14	7.8	1.3
b	C2	N	D	R	527	19	4.2	1.2
a	C2	N	U	L	551	17	4.3	1.2
a̲	C2	N	U	R	566	12	4.2	1.1

LEVERS (T1- T2)



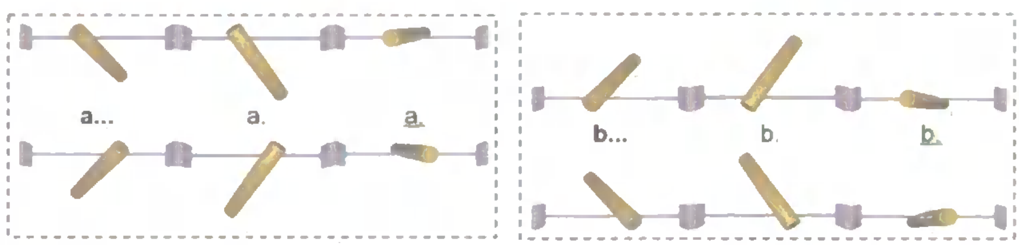


Figure 6.14 Mean RTs (black) and mean mistakes (red) as a function of X-Z bar position, Y-Z cylinder orientation, hand of response and mapping rule (n.b. MR: C2 in this figure)

For responses that made the lever move upwards (MR: C1= left responses, MR: C2 = right responses) the following pattern was observed: When the cylinder was oriented downwards in the Y-Z plane, mean RTs were faster (left = 19 ms, right = 19 ms) and mean mistakes were fewer (left = 3.3 %, right = 0.5 %) when the bar position was near rather than far. When the cylinder was oriented upwards in the Y-Z plane, mean RTs were faster (left = 74 ms, right = 71 ms) and mean mistakes were fewer (left = 3.5 %, right = 1.3 %) when the bar position was far rather than near.

For participants responses that made the lever move downwards (MR: C1 = right responses, MR: C2 = left responses) the following pattern was observed: When the cylinder was oriented downwards in the Y-Z plane, mean RTs were faster (left = 41 ms, right = 54 ms) and mean mistakes were fewer (left = 4.2 %, right = 3.5 %) when the bar position was far rather than near. When the cylinder was oriented upwards in the Y-Z plane, mean RTs were faster (left = 5 ms, right = 8 ms) and mean mistakes were fewer (left = 4.3 %, right = 1.3 %) when the bar position was near rather than far.

The overall pattern suggested an advantage for responses that effected a short (rather than long) lever movement (regardless of whether this was made with a left or right hand response owing to mapping rule conditions). It can be speculated that the basis of this effect lay in either the possibility that a) making a short lever movement would be (in real physical terms) less demanding than making a long lever movement and that this biomechanical difficulty was coded by the visuomotor representation; or b) imagining a short lever movement would take a shorter time than imagining a long lever movement, and that this was reflected by the duration of (action-neutral) cognitive processing needed to determine a response. On closer inspection, it appears that there was a clearly identifiable gradation of effect size corresponding to the actual physical difficulty of moving particular lever configurations. This possibility is discussed in section 6.4.3.

6.4.3 Discussion

There are a number of results relating to the mapping rule from this experiment that are apparently obscure. In order to understand the often-complex data relating to the mapping rule, the inclusion of certain other variables is crucial. When these variables are missing, interpretation is difficult, if not futile. For example, when the mapping rule is present in an interaction (thus potentially providing information about whether the lever was moved up or down by a left or right hand of response), it is necessary also to have hand of response as an interacting variable (in order to explain what actually happened to a given lever). The interaction between X-Z bar position and various cylinder component orientations (results [6.3.5a&b and 6.3.6a&b] reported in Appendix 2) behaved differently under each mapping condition. However, because these results were collapsed across spatial responses, one cannot tell what actually happened to a given lever. Similarly, when both mapping rule and hand of response are present in an interaction (thus potentially providing information about exactly what happened to a given lever), it is necessary also to have X-Z bar position as an interacting variable (in order to describe which end of a lever was free, and hence moved up or down). The interaction between hand of response and various cylinder component orientations (results [6.3.7 and 6.3.8] reported in Appendix 2) behaved differently under each mapping condition, yet because this data was collapsed across X-Z bar positions, specific lever configurations cannot be examined.

Nevertheless, result [6.3.10↯] *does* provide all of the information needed to make sense of how each lever behaved under each mapping condition. Indeed, this result contains some relatively large effect sizes, and it is likely that those otherwise obscure effects relating to mapping rule are simply by-products of this crucial result, carried over to significance thanks to the large effect sizes involved. As such this discussion will ignore those 'obscure' results in favour of those that are open to meaningful interpretation, such as result [6.3.10↯]. Those results that do present themselves as interpretable all share one common theme- they all point to performance-related benefits that are associated with the kinds of actions that might be directed towards a given lever, were one to actually physically interact with them.

[6.3.1✓] X-Z bar position

The first result of interest was the main effect of X-Z bar position in RTs. Here, mean RTs were faster when the bar position was far (in the background) rather than near (in the foreground). In terms of action possibilities, it is apparent that when the position of the bar was far, would-be-reaches to the cylinder component would be unrestricted. However, when the position of the bar was near, the obstacle of the bar would potentially restrict would-be-reaches towards (and possible movements of) the cylinder component.

[6.3.4✓] X-Z bar position × Y-Z cylinder orientation

The second result of interest was the interaction between X-Z bar position and Y-Z cylinder orientation [6.3.4a✓]. Here the Y-Z cylinder orientation was associated with either fast or slow RTs depending on whether the X-Z bar position was near or far. The apparent basis for this interaction lay in the kind of reach that one might make towards the free end of the cylinder component of a given lever. This can be seen in Figure 6.15, where arms have been embedded in the lever displays in an attempt to portray the sort of action that might be required were one to physically interact with a given lever. These arm illustrations are of course an approximation, and the arm: lever ratio has been arbitrarily chosen. Nevertheless, they do suggest that in terms of action, the pattern of RTs can be explained in terms of the direction of a required reach trajectory. Those levers that would require an upward reach trajectory (levers b & d) were responded to faster than those levers that would require a downward reach trajectory (levers a & c). Thus the pattern of RTs was as follows: levers b (530 ms) < levers a (539 ms); levers d (506 ms) < levers c (515 ms). This trend held for each specific lever configuration also, as reflected by the equivalent result [6.3.4b✓] reported in Appendix 2, where those specific levers that would require an upward reach trajectory (levers 3-6) were responded to faster than those levers that would require a downward reach trajectory (levers 1, 2, 7 & 8). Thus the pattern of RTs was as follows: lever 3

(526 ms) < lever 1 (541 ms); lever 4 (533 ms) < lever 2 (537 ms); lever 5 (505 ms) < lever 7 (513 ms); lever 6 (507 ms) < lever 8 (518 ms).

Interestingly, this result related to a main effect of Y-Z cylinder orientation found in Experiments 5.3 [5.3.3↗] and 6.2 [6.2.1↗]. In both cases there was an advantage for cylinders oriented upwards, and it was suggested that this might have reflected a preference for cylinders that would require an upward reach trajectory. The pattern of data currently under discussion provides some support for this notion, whereby those lever configurations that would require an upward reach trajectory held the advantage. Furthermore, it can be seen that the orientation of the cylinder component did not itself ensure this pattern. Instead what mattered was how this cylinder orientation interacted with the X-Z position of the bar, such that the whole lever configuration described significance for action.

From this perspective, it can be argued that a visuomotor primitive associated with Y-Z cylinder orientation (e.g. a representational 'default setting' that automatically potentiated aspects of an upward reach trajectory) has been *elaborated* (as predicted by the Task Context Hypothesis) in accordance with the context of a functional lever whose simple mechanics demand that the cylinder component be interacted with in a particular way (i.e. by grasping its free end). Crucially, the underlying function of this affordance is unchanged from that of the 'default setting' (i.e. its function is to afford upward reaches).

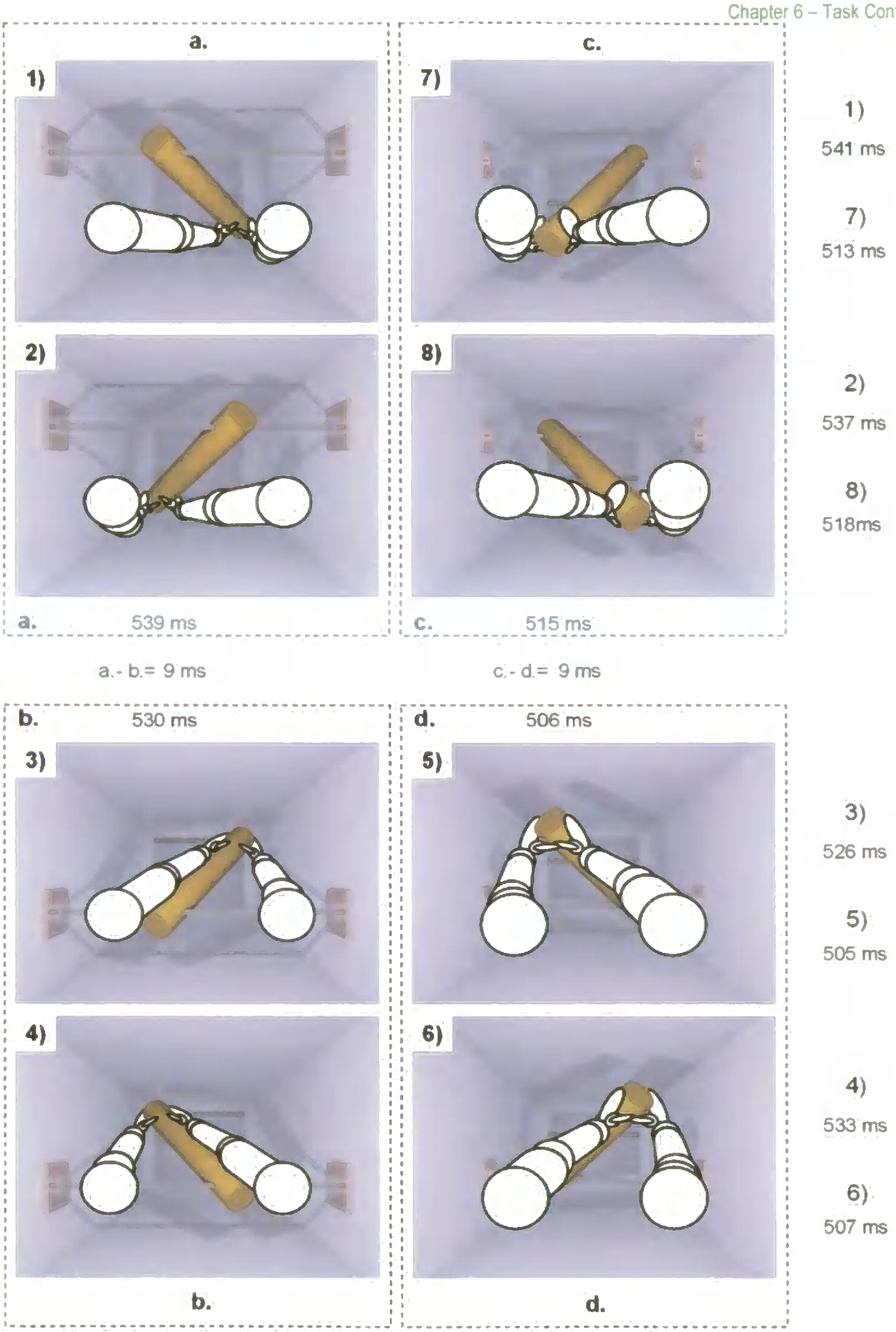


Figure 6.15 The levers involved in result [6.3.4✔], with approximate arm configurations displayed

[6.3.9 ✓] X-Z bar position × X-Z cylinder orientation × response

Following from the ideas discussed above, this result suggested a *modulation* (rather than elaboration) of a previously identified 'default setting' (again supporting the Task Context Hypothesis). Where Experiments 5.1- 5.3 and 6.1 consistently showed performance-related benefits for the hand of response that was on the same side as the nearest end of a cylinder in the X-Z plane, here the compatibility effect *reversed* such that the advantage was always for the opposite hand. It can be argued that the different action-context of a functionally unambiguous lever resulted in the modification of a representational default associated with the X-Z orientation of a functionally ambiguous cylinder. In short, it appears that the cylinder recommended a different type of interaction when it was part of a lever.

The apparent basis for this interaction between X-Z bar position, X-Z cylinder orientation and hand of response [6.3.9a✓] therefore lay in the kind of reach that one might make towards the free end of the cylinder component of a given lever (regardless of what movement might follow, since this result was collapsed across mapping conditions). This can be seen in Figure 6.16, which suggests that the pattern of mean RTs (and mistakes) can be explained in terms of the direction of a would-be-reach trajectory. <u>For left responses,</u> those levers that would require a contralateral reach with the left hand (levers a & d) were responded to faster and more accurately than those levers that would require an ipsilateral reach with the left hand (levers b & c). <u>For right responses</u>, those levers that would require a contralateral reach with the right hand (levers b & c) were responded to faster and more accurately than those levers that would require an ipsilateral reach with the right hand (levers a & d).

Thus the pattern of RTs and mistakes was as follows: <u>for left hand responses</u> levers a (538 ms, 4.7 %) < levers b (548 ms, 6.5 %) and levers d (519 ms, 4.3 %) < levers c (522 ms, 6.1 %); and <u>for right responses</u> levers b (522 ms, 4.1 %) < levers a (529 ms, 5.5 %) and levers c (497 ms, 3.0 %) < levers d (506 ms, 5.1 %). This trend held for each specific lever configuration also (except for one case in bold typeface), as reflected by the equivalent result reported in Appendix 2 [6.3.9b↯]. Here, those specific levers that would require contralateral reaches with a particular hand were responded to faster and more accurately than those levers that would require ipsilateral reaches with a particular hand. Thus the pattern of RTs and mistakes was as follows: <u>for left responses</u> lever 1 (548 ms, 4.2 %) < lever 2 (552 ms, 7.5 %); lever 3 (528 ms, 5.2 %) < lever 4 (545 ms, 5.5 %); lever 6 (513 ms, 5.0 %) < lever 5 (518 ms, 5.8 %) and lever 8 (**525** ms, 3.5 %) < lever 7 (**525** ms, 6.3 %); and <u>for right hand responses</u> lever 2 (522 ms, 3.7 %) < lever 1 (534 ms, 4.8 %); lever 4 (522 ms, 4.5 %) < lever 3 (525 ms, 6.2 %); lever 5 (493 ms, 3.5 %) < lever 6 (501 ms, 5.0 %) and lever 7 (501 ms, 2.5 %) < lever 8 (510 ms, 5.2 %).

Figure 6.16 The levers involved in result [6.3.9↗], with approximate arm configurations displayed

[6.3.10 ✓] Mapping rule × X-Z bar position × Y-Z cylinder orientation × response

In perhaps the most revealing result of this experiment, result [6.3.10a✓] has revealed new compatibility effects that included as interacting variables Y-Z cylinder orientation and hand of response. In Chapter 5, Visual Attribute Hypothesis 2 suggested that Y-Z cylinder orientation would not interact with hand of response, since they are not shared dimensions (i.e. upward/ downward is fundamentally incompatible with left/right). Indeed, all of the cylinder experiments have supported this hypothesis. However, within the context of an artificial perception-action coupling in which a lever moves up or down *as a consequence* of left and right hand responses, the same Y-Z orientation of a cylinder component now becomes highly relevant to left-right responses. Thus when other variables are considered (mapping rule and X-Z bar position), a highly context specific influence of Y-Z cylinder orientation on responses can be identified.

Such a high-order interaction (between mapping rule, X-Z bar position, Y-Z orientation and hand of response) is naturally complex and needs to be broken down into manageable parts (see Figs. 6.17-6.20). As a general observation, it can be seen in each figure that response performance (in both speed and accuracy) was always better for levers that had moved a short rather than long distance. This trend might reflect motor imagery sensitive to movement difficulty, since it would be physically easier to move a lever a short rather than a long distance. However, it could alternatively be argued that this pattern instead reflected the cognitive processing time taken to imagine (in an action-neutral manner) a lever moving a short or long distance. Under this view, long movements would take a longer time to imagine.

Remarkably however, a subtler pattern was apparent in the data, whereby lever movements appeared to be graded in terms of their physical difficulty relative to each other. This finding does not support an action-neutral cognitive processing time explanation, since the distances that a lever could move were identical for all levers (from its start position a lever either moved a long or short distance to the floor, or a long or short distance to the ceiling). In other words, since each lever could only move one of two distances (long or short), with absolutely no other variation of movement distance, then the cognitive processing time should be equally short for all levers that moved a short distance, and equally long for all levers that moved a long distance. However, as Figs. 6.17-6.20 suggest, the pattern of RTs reflected a gradation of differences between long and short lever movements, depending upon the lever configurations involved. Furthermore, the gradation of these differences appeared to correspond to the discrepancy in movement difficulty between these different levers, were one to actually physically move them. The following examines four identifiable patterns in the data.

Pattern 1: For example, when two kinds of lever movements were of a similar difficulty, the difference between them in terms of RTs was small. Thus in Figure 6.17, it can be seen that moving levers a. downwards a short distance (left responses: 551 ms, right responses: 490 ms) took on average **6 ms** (left responses) and **8 ms** (right responses) less than moving levers c. downwards a long distance (left responses: 557 ms, right responses: 498 ms).

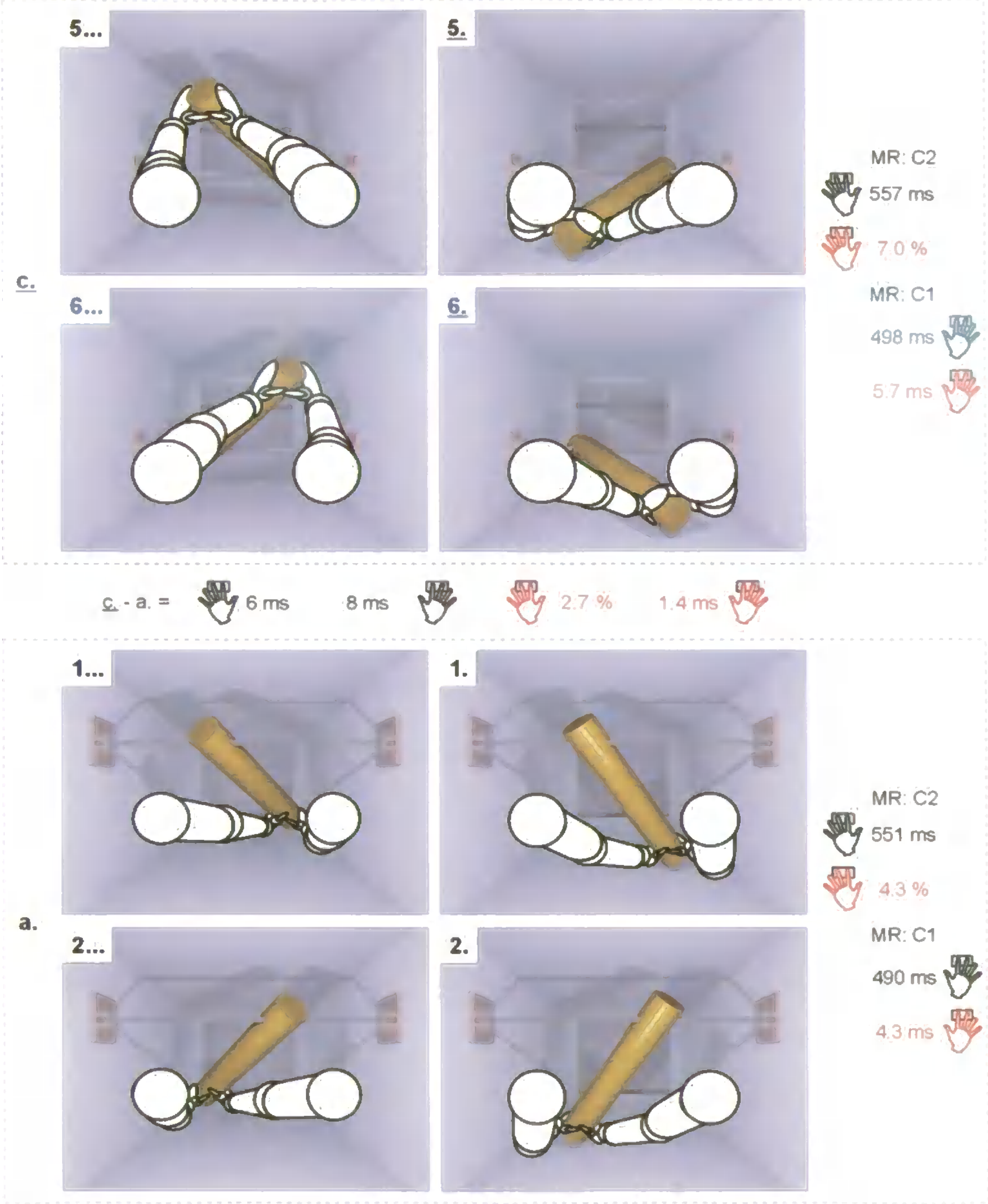


Figure 6.17 Pattern 1 of result [6.3.10a↗], with approximate arm configurations displayed

Pattern 2: However, in using different levers, when a long upward movement appeared to be physically more difficult than a short upward movement, then the differences between them in terms of RTs were slightly more pronounced. Thus in Figure 6.18, it can be seen that moving levers b. upwards a short distance (left responses: 505 ms, right responses: 527 ms) took on average **19 ms** (left responses) and **19 ms** (right responses) less than moving levers <u>d.</u> upwards a long distance (left responses: 524 ms, right responses: 546 ms).

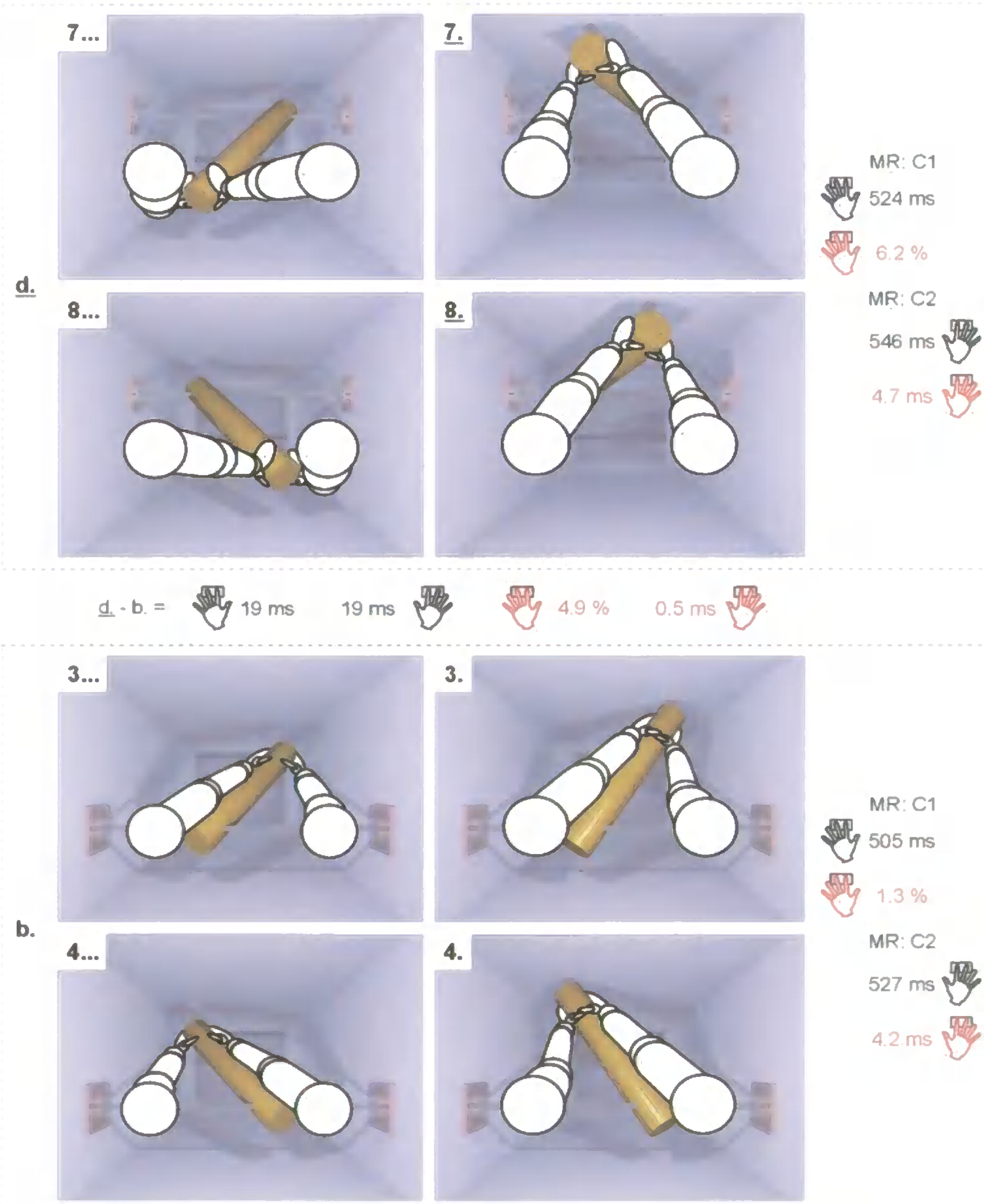


Figure 6.18 Pattern 2 of result [6.3.10a✓], with approximate arm configurations displayed

Pattern 3: When the discrepancy between movement difficulties increased further still, the difference between them in terms of RTs also increased. Thus in Figure 6.19, it can be seen that moving levers d. downwards a short distance (left responses: 526 ms, right responses: 466 ms) took on average **41 ms** (left responses) and **54 ms** (right responses) less than moving levers b. downwards a long distance (left responses: 567 ms, right responses: 520 ms).

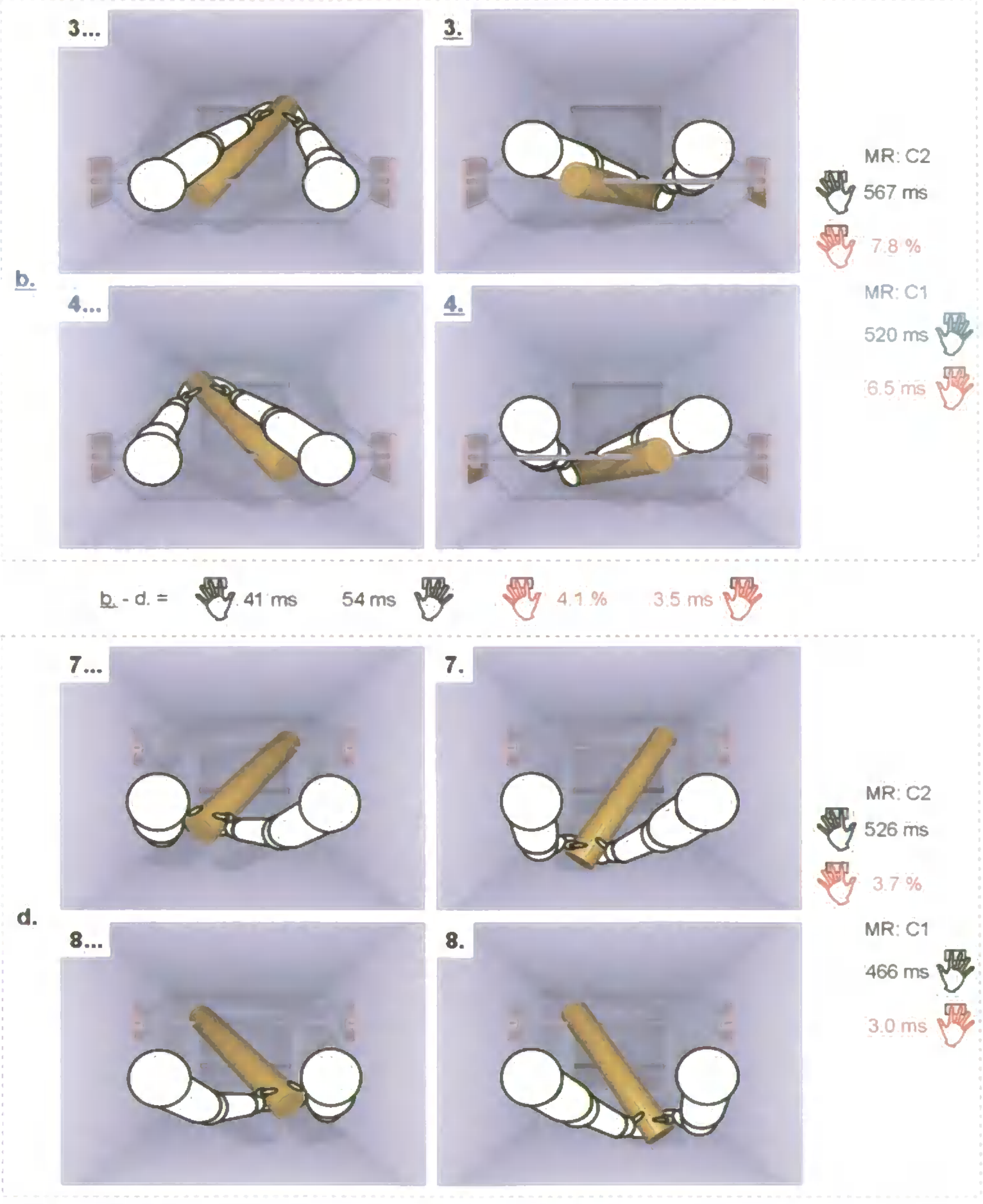


Figure 6.19 Pattern 3 of result [6.3.10a↗], with approximate arm configurations displayed

Pattern 4: Finally, when the discrepancy between movement difficulties was at its greatest, then the differences in RTs were at their greatest. Thus in Figure 6.20, it can be seen that moving levers c. upwards a short distance (left responses: 474 ms, right responses: 495 ms) took on average **74 ms** (left responses) and **71 ms** (right responses) less than moving levers a. upwards a long distance (left responses: 548 ms, right responses: 566 ms).

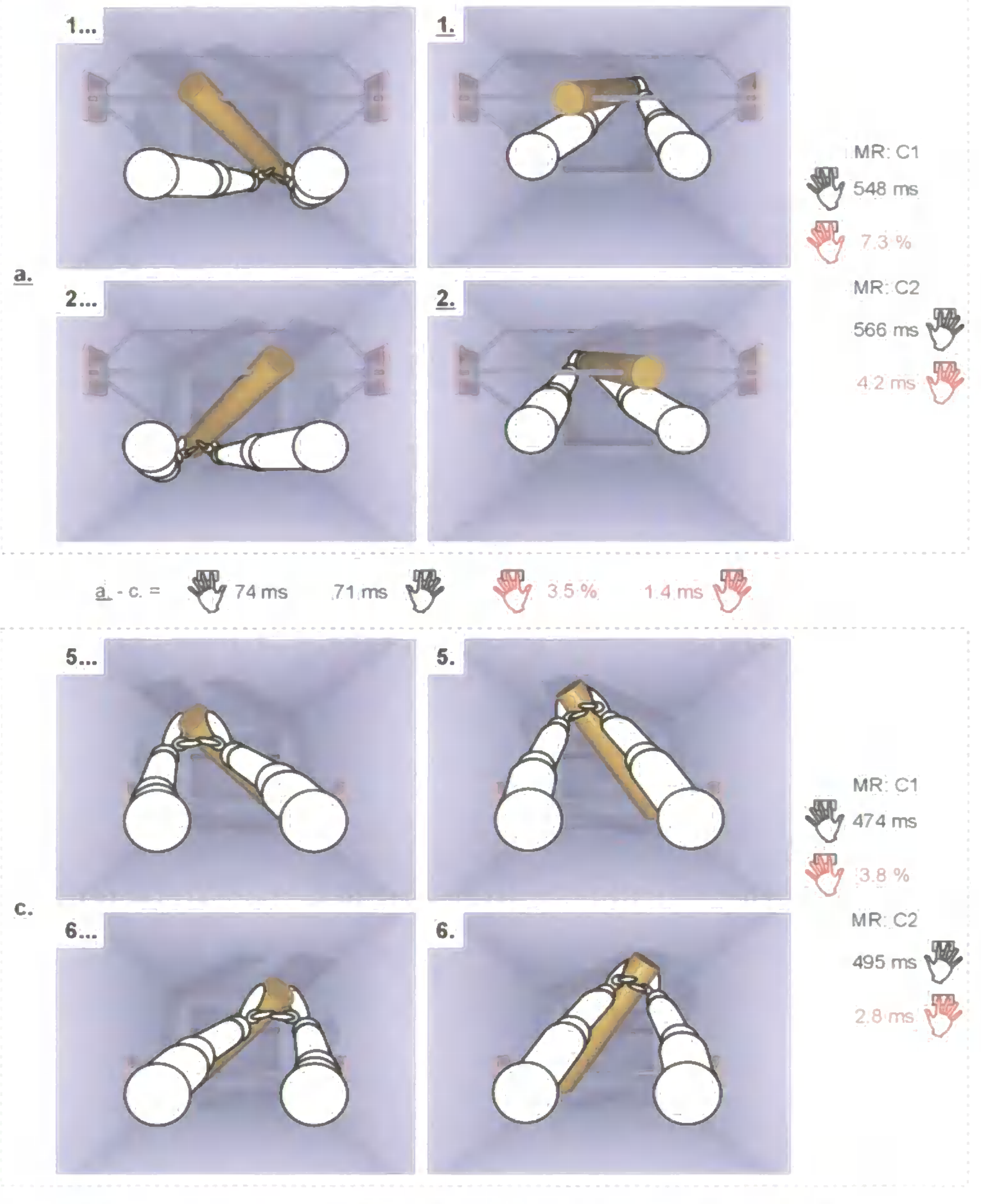


Figure 6.20 Pattern 4 of result [6.3.10a✓], with approximate arm configurations displayed

When responses to the specific lever configurations are considered (see result [6.3.10b✓] in Appendix 2), a further action-sensitive trend is apparent within each of the four patterns discussed above.

Lever specific pattern within Pattern 1:

The pattern of RTs for specific levers was as follows: for left responses, lever 5. (551 ms) - lever 1. (551 ms) = **0 ms** (smallest difference), and lever 6. (562 ms) - lever 2. (552 ms) = **10 ms** (largest difference). The opposite pattern occurred for right responses, such that lever 5. (499 ms) - lever 1. (484 ms) = **15 ms** (largest difference), and lever 6. (498 ms) - lever 2. (497 ms) = **1 ms** (smallest difference).

'Smallest difference' relations: Here, the two actions common to both arms were as follows: for long movements, a bent-armed downward ipsilateral pull; and for short movements, a straight-armed contralateral pull towards the body (see Figure 6.21). Relating to the left response RTs, it can be argued that the long movement of lever 5. was no harder to simulate than the short movement of lever 1. (the difference was **0 ms**). Relating to the right response RTs, it can be argued that the long movement of lever 6. was no harder to simulate than the short movement of lever 2 (the difference was **1 ms**).

'Largest difference' relations: In contrast, when the same levers are considered using the opposite responses, there was a **slight** difference in mean RTs. This increased difference (when compared to the previous 'smallest difference' relations) might reflect four mentally simulated actions, two (the long movements) that were slightly more complex (in terms of biomechanical constraints) to simulate than the other two (the short movements) - a possibility that seems to be supported by the relative difficulty of the different arm illustrations in Figure 6.22. The two actions common to both arms were as follows: for long movements, a straight-armed movement in a contralateral downward arc; and for short movements, a bent-armed ipsilateral pull towards the body. Relating to the left response RTs, it can be argued that the long movement of lever 6. was *slightly* harder to

simulate than the short movement of lever 2. (the difference was **10 ms**). Relating to the right response RTs, it can also be argued that the long movement of lever 5. was *slightly* harder to simulate than the short movement of lever 1. (the difference was **15 ms**).

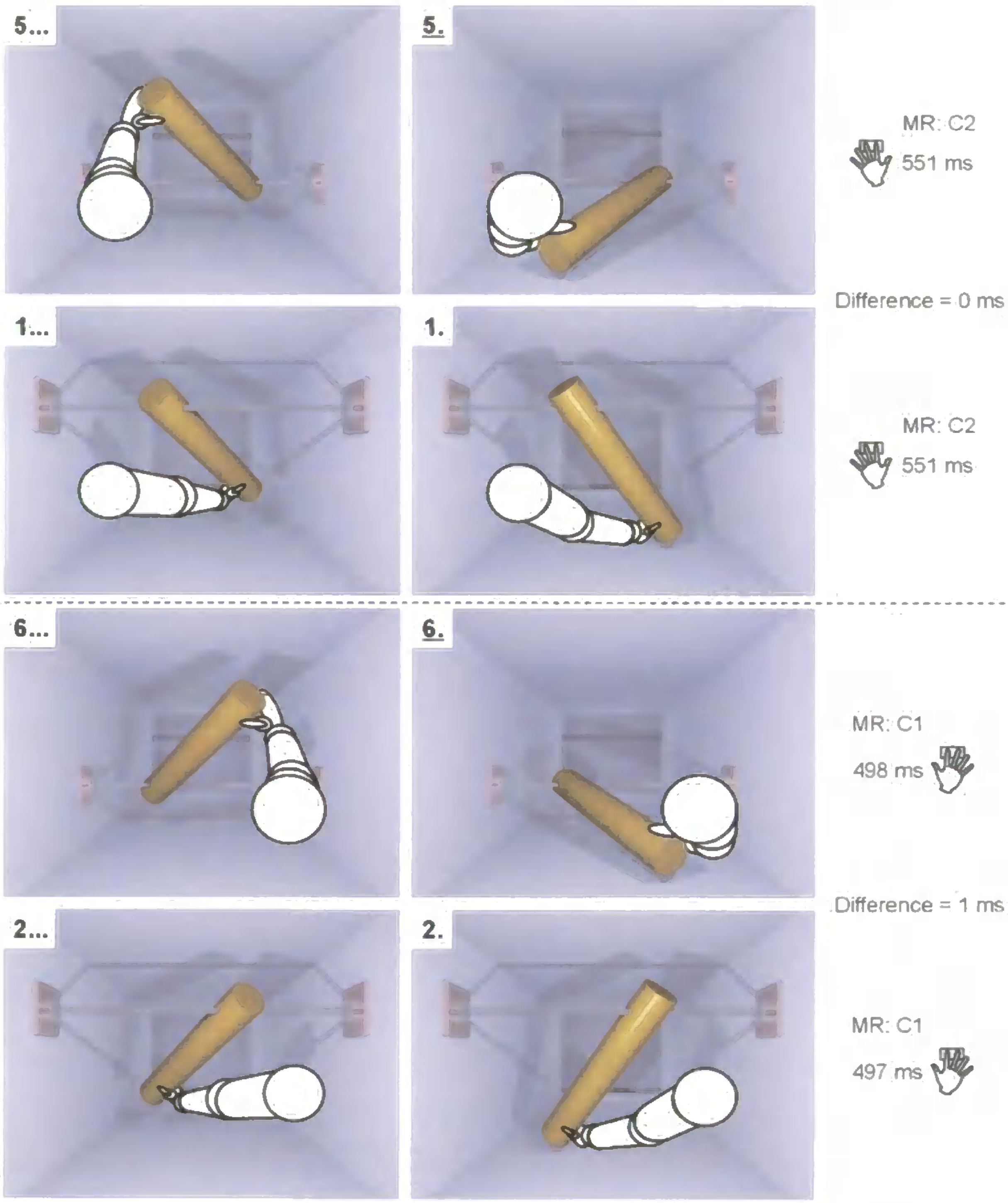


Figure 6.21 'Smallest difference relations' from Pattern 1, with approximate arm configurations displayed

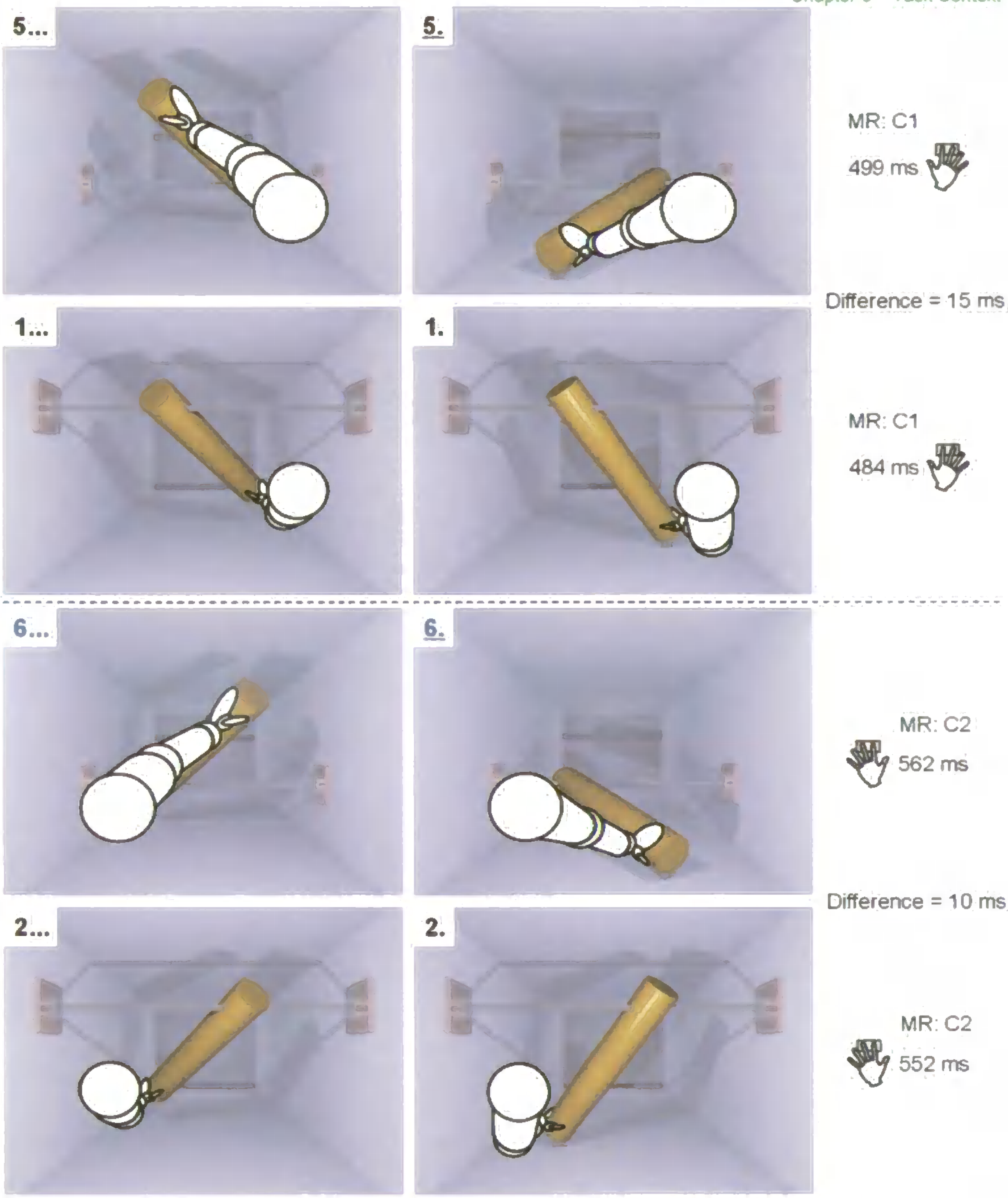


Figure 6.22 'Largest difference relations' from Pattern 1, with approximate arm configurations displayed

Lever specific pattern within Pattern 2:

Similarly, the pattern of RTs for specific levers was as follows: for left responses, lever 8. (525 ms) - lever 4. (514 ms) = **11 ms** (smallest difference), and lever 7. (524 ms) - lever 3. (496 ms) = **28 ms** (largest difference). The opposite pattern occurred for right responses, such that lever 8. (553 ms) - lever 4. (529ms) = **24 ms** (largest difference), and lever 7. (539 ms) - lever 3. (525 ms) = **14 ms** (smallest difference).

'Smallest difference' relations: Here, there was a **slight** difference in mean RTs. This difference might reflect four mentally simulated actions, two (the long movements) that were slightly more complex (in terms of biomechanical constraints) to simulate than the other two (the short movements) - a possibility that seems to be supported by the arm illustrations in Figure 6.23. The two actions common to both arms were as follows: for long movements, a straight-armed upward contralateral push; and for short movements, a bent-armed ipsilateral pull towards the body. Relating to the left response RTs, it can be argued that the long movement of lever 8. was *slightly* harder to simulate than the short movement of lever 4. (the difference was **11 ms**). Relating to the right response RTs, it can be argued that the long movement of lever 7. was *slightly* harder to simulate than the short movement of lever 3 (the difference was **14 ms**).

'Largest difference' relations: In contrast, when the same levers are considered using the opposite responses, there was a **considerable** difference in mean RTs. This increased difference (when compared to the previous 'smallest difference' relations) might reflect four mentally simulated actions, two (the long movements) that were considerably more complex (in terms of biomechanical constraints) to simulate than the other two (the short movements) - a possibility that seems to be supported by the arm illustrations in Figure 6.24. The two actions common to both arms were as follows: for long movements, a bent-armed ipsilateral upward push; and for short movements, a straight-armed contralateral pull towards the body. Relating to the left response RTs, it can be argued that the long

movement of lever 7. was *considerably* harder to simulate than the short movement of lever 3. (the difference was **28 ms**). Relating to the right response RTs, it can also be argued that the long movement of lever 8. was *considerably* harder to simulate than the short movement of lever 4. (the difference was **24 ms**).

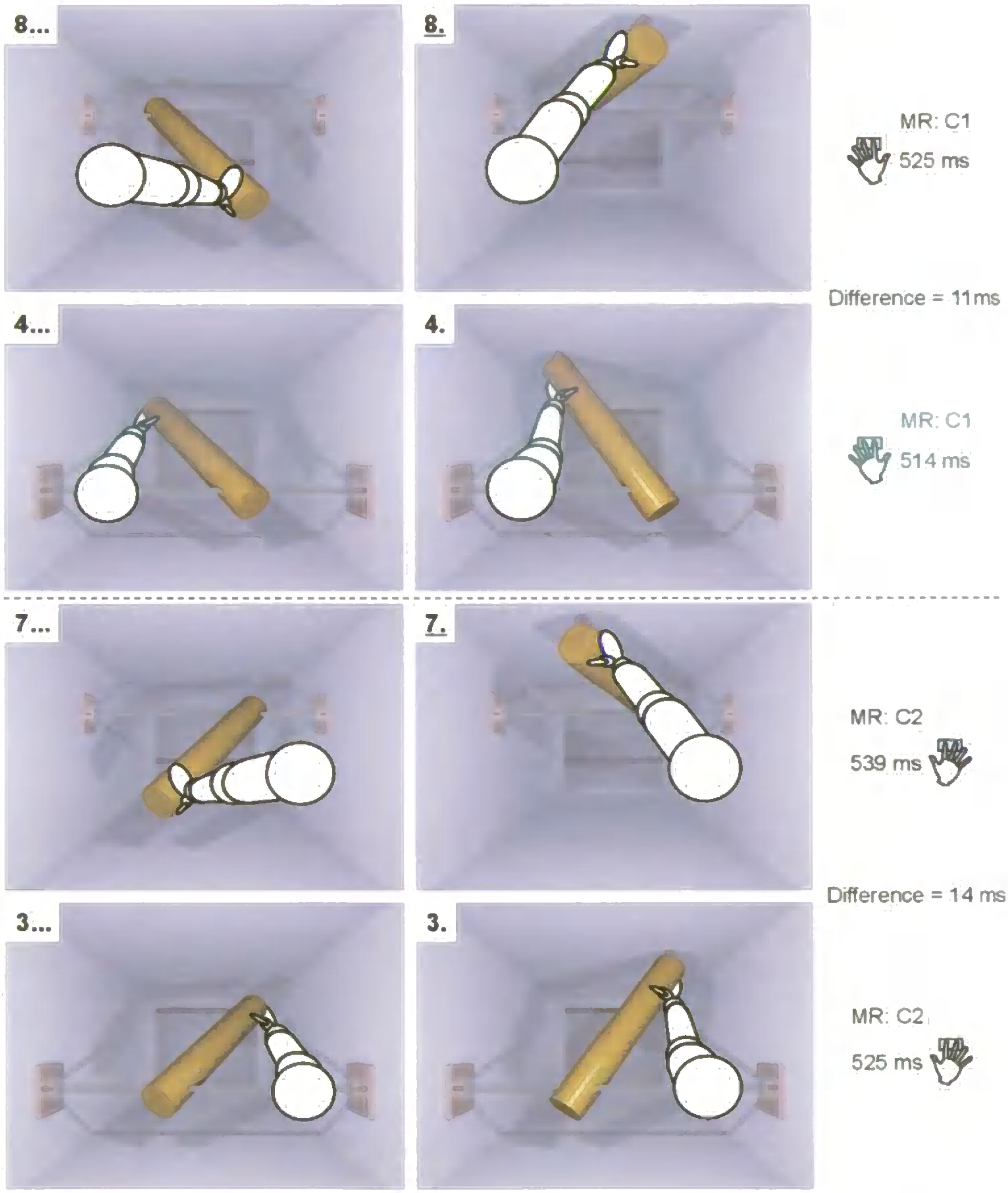


Figure 6.23 'Smallest difference relations' from Pattern 2, with approximate arm configurations displayed

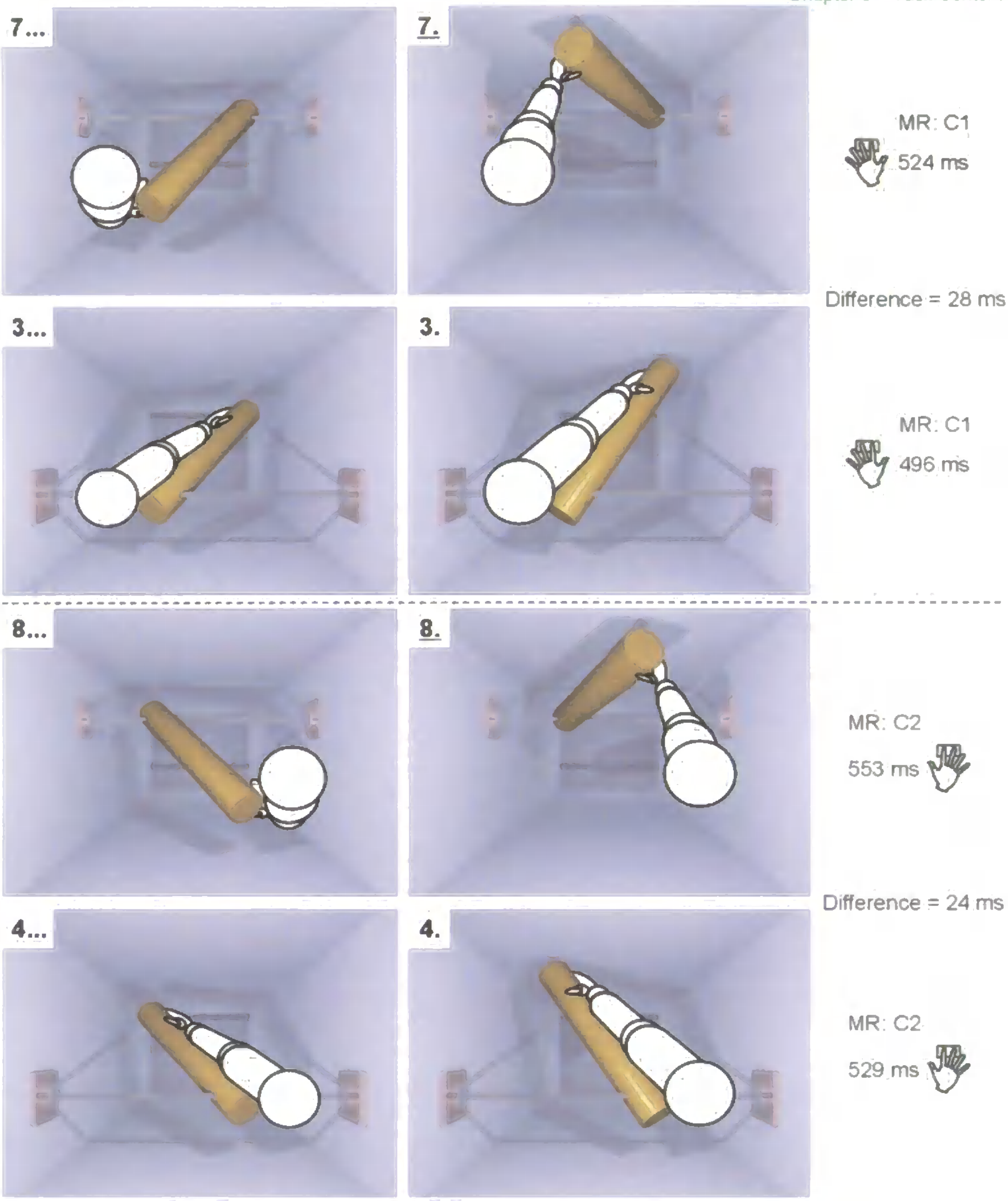


Figure 6.24 'Largest difference relations' from Pattern 2, with approximate arm configurations displayed

Lever specific pattern within Pattern 3:

Similarly, the pattern of RTs for specific levers was as follows: for left responses, lever 3. (559 ms) - lever 7. (527 ms) = **32 ms** (smallest difference), and lever 4. (575 ms) - lever 8. (525 ms) = **50 ms** (largest difference). The opposite pattern occurred for right responses, such that lever 3. (524 ms) - lever 7. (464 ms) = **60 ms** (largest difference), and lever 4. (515 ms) - lever 8. (468 ms) = **47 ms** (smallest difference).

'Smallest difference' relations: Here, there was a **considerable** difference in mean RTs. This difference might reflect four mentally simulated actions, two (the long movements) that were considerably more complex (in terms of biomechanical constraints) to simulate than the other two (the short movements) -a possibility that seems to be supported by the arm illustrations in Figure 6.25. The two actions common to both arms were as follows: for long movements, a straight-armed downward contralateral push; and for short movements, a bent-armed downward ipsilateral push. Relating to the left response RTs, it can be argued that the long movement of lever 4. was *considerably* harder to represent than the short movement of lever 8. (the difference was **32 ms**). Relating to the right response RTs, it can be argued that the long movement of lever 3. was *considerably* harder to represent than the short movement of lever 7. (the difference was **47 ms**).

'Largest difference' relations: In contrast, when the same levers are considered using the opposite responses, there was a **substantial** difference in mean RTs. This increased difference (when compared to the previous 'smallest difference' relations) might reflect four mentally simulated actions, two (the long movements) that were substantially more complex (in terms of biomechanical constraints) to simulate than the other two (the short movements); a possibility that seems to be supported by the arm illustrations in Figure 6.26. The two actions common to both arms were as follows: for long movements, a bent-armed downward ipsilateral push; and for short movements, a straight-armed downward contralateral push. Relating to the left response RTs, it can be argued that the long

movement of lever 4. was *substantially* harder to simulate than the short movement of lever 8. (the difference was **50 ms**). Relating to the right response RTs, it can also be argued that the long movement of lever 3. was *substantially* harder to simulate than the short movement of lever 7. (the difference was **60 ms**).

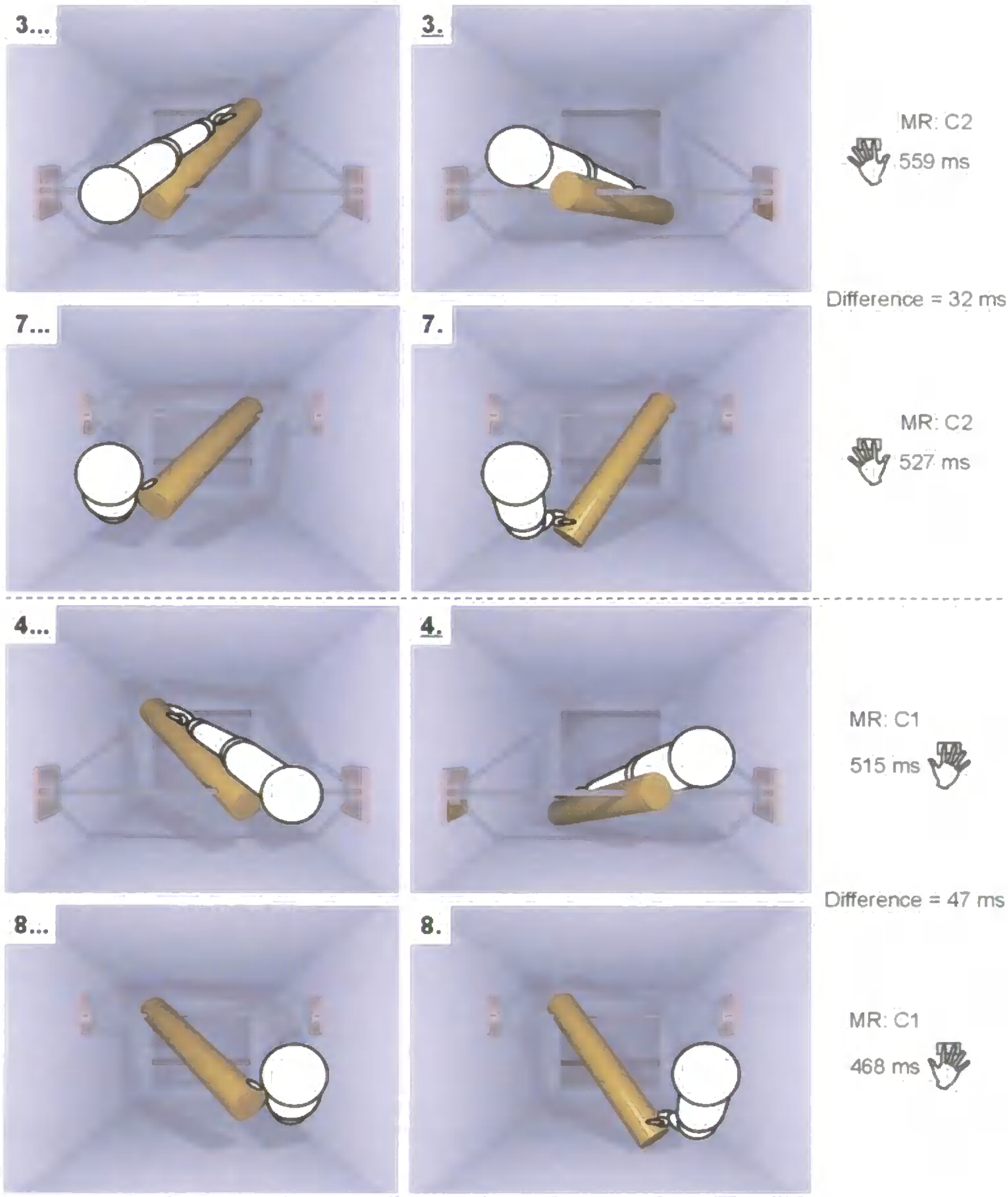


Figure 6.25 'Smallest difference relations' from Pattern 3, with approximate arm configurations displayed

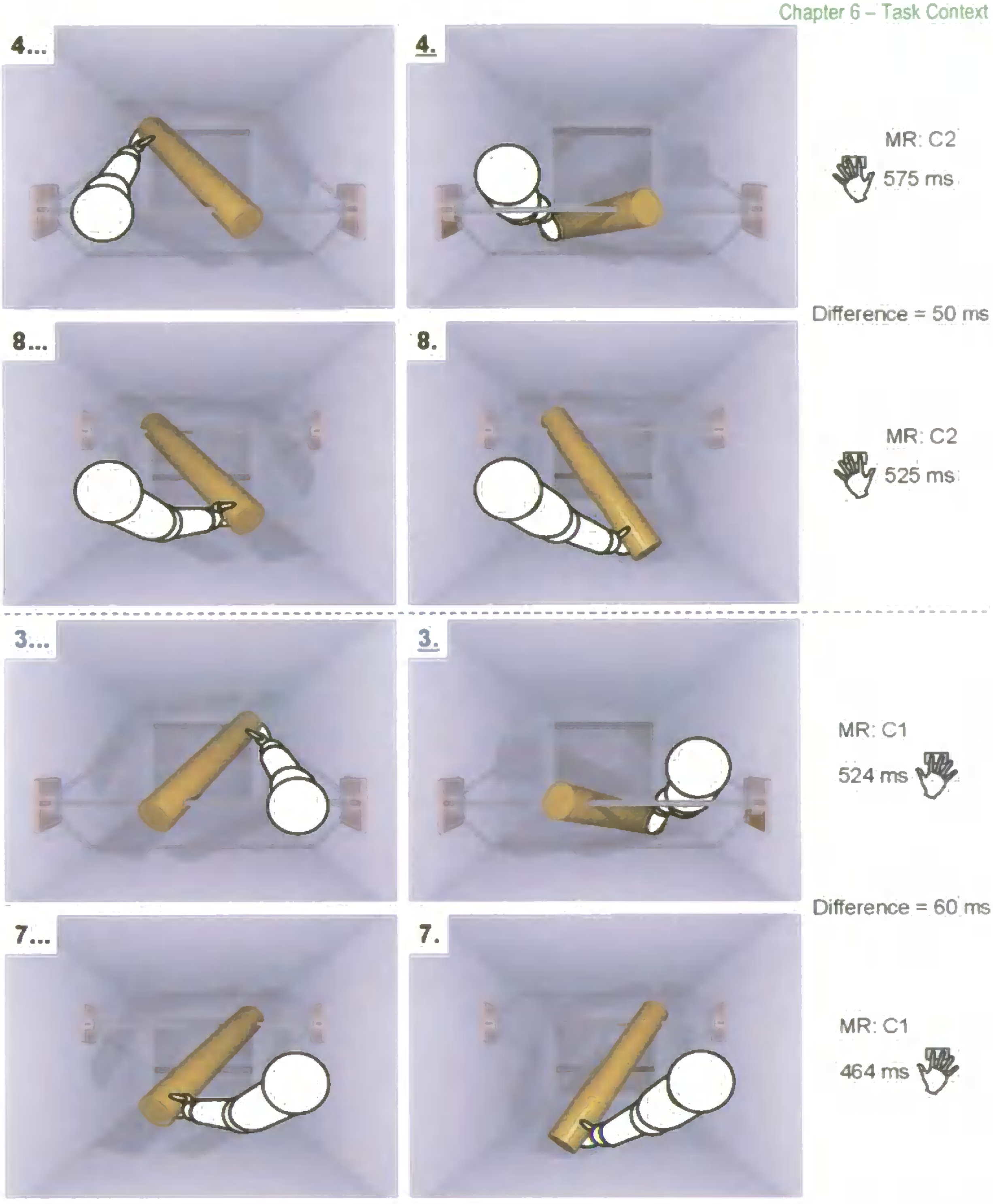


Figure 6.26 'Largest difference relations' from Pattern 3, with approximate arm configurations displayed

Lever specific pattern within Pattern 4:

Similarly, the pattern of RTs for specific levers was as follows: for left responses, lever 1. (545 ms) - lever 5. (485 ms) = **60 ms** (smallest difference), and lever 2. (552 ms) - lever 6. (463 ms) = **89 ms** (largest difference). Similarly, for right responses, lever 1. (584 ms) - lever 5. (487 ms) = **97 ms** (largest difference), and lever 2. (548 ms) - lever 6. (503ms) = **45 ms** (smallest difference).

'Smallest difference' relations: Here, there was a **substantial** difference in mean RTs. This difference might reflect four mentally simulated actions, two (the long movements) that were substantially more complex (in terms of biomechanical constraints) to simulate than the other two (the short movements) -a possibility that seems to be supported by the arm illustrations in Figure 6.27. The two actions common to both arms were as follows: for long movements, a straight-armed upward contralateral push; and for short movements, a bent-armed upward ipsilateral push. Relating to the left response RTs, it can be argued that the long movement of lever 1. was *substantially* harder to simulate than the short movement of lever 5. (the difference was **40 ms**). Relating to the right response RTs, it can be argued that the long movement of lever 2. was *substantially* harder to simulate than the short movement of lever 6. (the difference was **45 ms**).

'Largest difference' relations: In contrast, when the same levers are considered using the opposite responses, there was a **dramatic** difference in mean RTs. This increased difference (when compared to the previous 'smallest difference' relations) might reflect four mentally simulated actions, two (the long movements) that were dramatically more complex (in terms of biomechanical constraints) to simulate than the other two (the short movements) - a possibility that seems to be supported by the arm illustrations in Figure 6.28. The two actions common to both arms were as follows: for long movements, a bent-armed upward ipsilateral push; and for short movements, a straight-armed upward contralateral push. Relating to the left response RTs, it can be argued that the long

movement of lever 1. was *dramatically* harder to simulate than the short movement of lever 5. (the difference was **97 ms**). Relating to the right response RTs, it can also be argued that the long movement of lever 2. was *dramatically* harder to simulate than the short movement of lever 6. (the difference was **89 ms**).

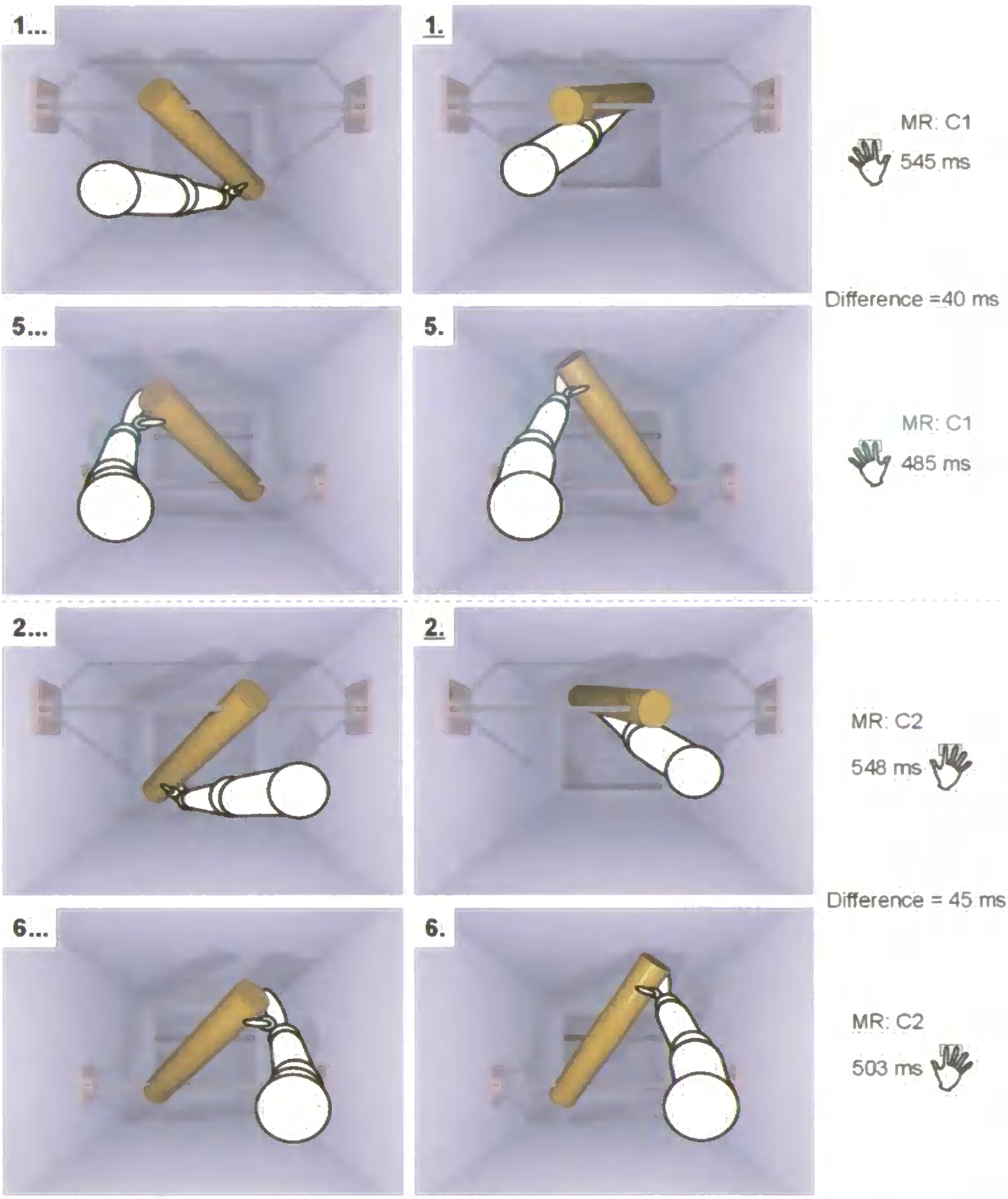


Figure 6.27 'Smallest difference relations' from Pattern 4, with approximate arm configurations displayed

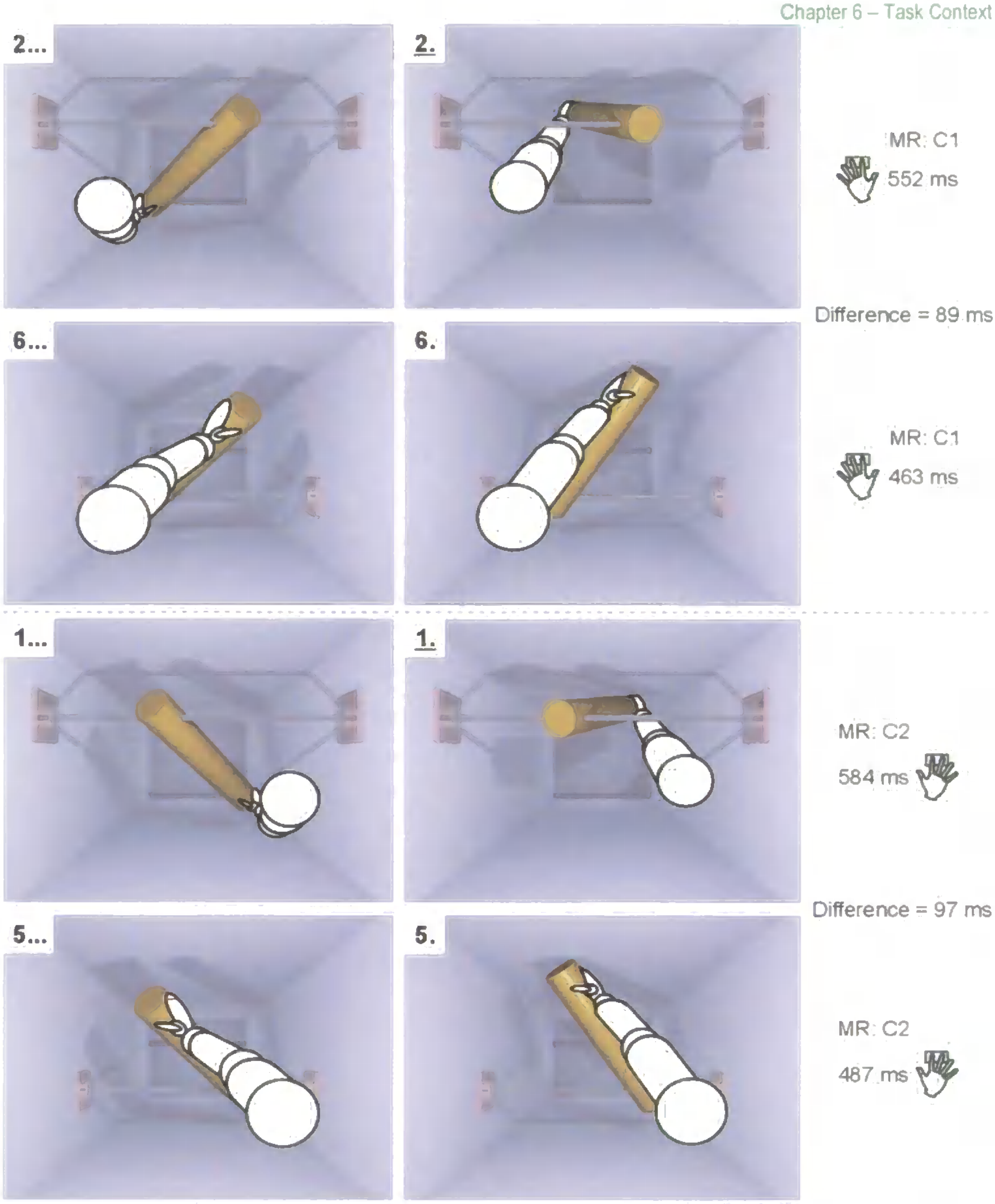


Figure 6.28 'Largest difference relations' from Pattern 4, with approximate arm configurations displayed

In conclusion, the clearly graded nature of the perception-action compatibility effects found in result [6.3.10✓] supported the possibility that the movement of a lever was imagined using motor imagery (i.e. the would-be-actions were simulated). Furthermore these action simulations were sensitive to the biomechanical difficulty or awkwardness of these would-be-actions. This was reflected by the size of differences (in mean RTs) between responses that produced two types of lever movements (long and short). Using the arm illustrations as a conceptual aid, it appeared likely that the slower the RTs were, the more complex the simulations were (e.g. those associated with difficult or awkward lever movements); and that the faster the RTs were, the less complex the simulations were (e.g. those associated with easy or comfortable lever movements). In taking the two simplest extremes (patterns 1 and 4) as an example (which did not look at specific levers, but rather focussed on the Y-Z plane of the cylinder component), the following summary observation can be made: When the discrepancy in difficulty between two lever movements was small (e.g. an easy/comfortable short movement and an easy/comfortable long movement), then the discrepancy in RTs was small (e.g. RTs relating to Pattern 1.). On the other hand, when the discrepancy in difficulty between two levers was large (e.g. an easy/comfortable short movement and a difficult/awkward long movement), then the discrepancy in RTs was large (e.g. RTs relating to Pattern 4.). The relative discrepancy in difficulty between classes of lever movements for Patterns 2 and 3 fell somewhere in between these two extremes.

6.5 General Discussion of Experiments 6.1-6.3

Experiments 6.1-6.3 investigated whether the reliable trends found in Chapter 5 (most notably, the compatibility effect between X-Z cylinder orientation and response; the lack of a compatibility effect between X-Y cylinder orientation and response and the lack of a compatibility effect between Y-Z cylinder orientation and response) would change in some way when the task context was manipulated. This investigation aimed to demonstrate that action-oriented representations are not highly prescriptive and fixed, but rather reflect loosely constrained mechanisms that can adjust to a range of viable actions that are appropriate within a current behavioural context. Thus the Task Context Hypothesis predicted that changing task context might a) reveal new perception-action compatibility effects, and/or b) alter the nature of previously established perception-action compatibility effects. This hypothesis was supported by all three experiments.

In Experiment 6.1, the time-to-response was manipulated by using different SOA's. It was argued that because the task context was not changed in such a way that new intentions or goals were formed, the activity of the automatically activated 'default' remained more-or-less stable (hence the different SOAs did not change the nature or size of the compatibility effect associated with X-Z cylinder orientation and response). It was suggested that the visuomotor system was nevertheless 'hungry' for new sources of action-relevant information, and that those spare resources that might otherwise have enhanced this default were deployed to 'seek out' new possibilities for action. This appeared to occur at SOA's of 800 ms (which gave the system time to deploy spare resources), and took the form of a *new* compatibility effect associated with the X-Y cylinder orientation and hand of response.

Experiment 6.2, which gave cylinders a dynamic feel by making them apparently move towards the viewer, had the effect of wiping out the normally reliable compatibility effect associated with X-Z cylinder orientation and hand of response. It is possible that this 'default' affordance was simply *eradicated*; or alternatively, a newfound pressure to withdraw from the visually looming cylinder may have *overridden* this default.

Experiment 6.3 changed the action-context of a cylinder by making it a mere component in a functioning lever-like device. A previous 'default' affordance associated with Y-Z cylinder orientation found in Experiments 5.3 and 6.2 (where upward reaches were advantaged) appeared to have been *elaborated*, such that the basic function of affording upward reaches was maintained by changing the influence of Y-Z cylinder orientation depending on how it behaved with respect to the bar component of the lever. In addition, the reliable 'default' affordance associated with X-Z cylinder orientation and response appeared to have been *modulated* (the direction of the compatibly effect reversed), such that the cylinder now recommended a different type of interaction in its new context as part of a functioning lever.

Finally, a new and intricate compatibility effect was revealed that was in part associated with Y-Z cylinder orientation and response. In the cylinder experiments of Chapter 5, Y-Z cylinder orientation did not interact with responses- presumably because there was no compatibility to be found between upward-downward orientation and left-right response. However, in the context of left and right responses that moved the cylinder component of a lever upwards and downwards, there was a newfound basis for compatibility. The context of engaging in a specific behavioural activity (effecting the movement of a virtual lever) appeared to have implicated a sophisticated simulation of action that was sensitive to biomechanical constraints. Johnson (2000a) also concluded that motor imagery was sensitive to various biomechanical constraints. However, one major respect in which this experiment differed from Johnson's was in its arbitrary mapping rule. In Johnson's studies participants made judgements or chose actions based on how comfortable they thought an action might be with respect to a real or graphically rendered wooden dowel that was variously oriented in the X-Y plane. In the current experiment however, there was no explicit reference to actions (e.g. reaches or grasps) or their likely comfort. In this light, it can be claimed that the sensitivity to movement difficulties found in this experiment is more likely to have reflected automatic, affordance-like processes. Rather than participants who were instructed to imagine how comfortable a movement might be (and who employed motor imagery to achieve this; as appeared to be the case in Johnson's studies); it appeared that participants in this study could not help but consider (in an action simulation sense) the biomechanical constraints of different movements, even though to do so was *completely task-irrelevant*.

Interestingly, this candidate affordance appeared to be considerably more specific than might be expected under a more generic 'representational default setting'. Indeed, this makes good sense, for a representational default is just that- a default. With all things being equal, it offers an adequate potentiation for action (that is general enough to influence a whole range of actions). However, in the lever experiment all things were not equal. There was a specific behavioural context within which to interact with a lever, and default settings were no longer adequate (although as we have seen in results [6.3.4↯ & 6.3.9↯], the origins of these defaults were arguably still detectable). Rather, what was needed was a more tightly constrained affordance for a specific behavioural activity, and far greater representational sophistication was needed.

7. Summary and conclusions

Contents

7.1 Summary and recommendations

This final chapter offers a summary of the previous six chapters, and for each experimental chapter (Chapters 3-6) recommendations are made for further investigations. Implications that the current data has for the attention-directing hypothesis are discussed, and finally, some concluding remarks are made that evaluate how the work of this thesis has contributed to our understanding of affordances.

7.1.1 Introduction (Chapter 1)

In setting the context for this thesis, Chapter 1 outlined two different traditions in visual perception. The computational tradition (which endeavours to explain how the brain constructs abstract general-purpose descriptions of the world) was criticised for its assumption that these descriptions or 'representations' are a separate endeavour to acting in the world. Born from this failure to consider the sensorimotor system, computationally intensive translation processes are required to allow perception to guide actions. This is epitomised by the convention of assuming separate and linear processing stages (input -> translation -> output). In contrast, the ecological tradition does not consider perception and action as separate endeavours. However, this tradition was criticized because although it rejects traditional notions of representation, it provides no satisfactory alternative. Nevertheless, the notion of a process-driven perception-action loop with operational closure was considered an important departure from linear-stage models. The notion of mental representation was given detailed theoretical and philosophical consideration, culminating in a meritorious alternative to traditional representations, namely action-oriented representations. Action-oriented representations both describe a situation and suggest an appropriate reaction to it without requiring mediating computations. This is the essence of a hypothesis that has received considerable attention throughout the thesis, namely the Action Potentiation Hypothesis. According to Tucker and Ellis' (1998) APH, representing a visual object involves simultaneously encoding information about the visual attributes of that object and components of the actions that one might perform on it.

7.1.2 Seeing the wood for the trees (Chapter 2)

This chapter adopted a wider perspective on thinking, perceiving and acting in general, by examining in depth a range of contemporary theories and approaches (e.g. separable but linked approaches to perception and action, particularly concerning the two visual systems; a theory of sensorimotor contingencies; the Enactive Approach; TNGS; a two-stage model of action control; and TEC). These theories and approaches share the common goal of attempting to unify our superficially distinct capacities for thought, simulation, perception and action (or at the very least, explain how they interact). This perspective is broadly known as 'Embodied Cognition', and fulfils much of the criteria demanded by a perception-action loop model of cognition. Of particular interest was the idea that there is a 'middle' level of perceptual processing in which amodal or 'common codes' allow the unification or interaction of these different capacities. The experimental chapters that followed drew heavily on the insights gained from an embodied approach to cognition by investigating different sources of perception-action couplings. These investigations focussed primarily on the direct relationship between the orientation of visual objects and simplistic left-right actions made towards some arbitrary property of these objects.

7.1.3 The Action Potentiation Hypothesis (Chapter 3)

As a clear example of an action-oriented representation, the APH's 'micro-affordance' was shown to be complementary to all of the 'middle way' perspectives discussed in the Chapter 2. In particular the notion of visuomotor primitives (that may be common components of a range of different actions) appeared to sit nicely with the 'middle way' and especially with the concept of a 'common code'. However, an examination of the sources of evidence offered by the APH revealed several ambiguities. These ambiguities centred on the possible extent to which a) so-called 'micro-affordances' are evoked in a default-like manner purely by visual attributes of an object (and if so, what are these visual attributes), and b) whether these micro-affordances are prescribed and fixed (such that they might relate exclusively to a specific component of a specific action), or whether they are more loosely constrained such that they might be modulated by behavioural and activity-based context (such that a range of actions might be affected, and in different ways depending on the context of a task). Addressing these ambiguities was the major aim of the experimental chapters that followed, as reflected by four experimental objectives. The objective for Chapter 3 (Objective 1) was as follows:

Objective 1: To replicate a study by Symes (1999) where object location and object orientation compatibility effects were obtained using left and right hand key-press responses to photographs of everyday objects. In this replication however, left and right responses are made with the feet, thus testing the hypothesis that a range of left-right actions can produce orientation-action compatibility effects.

The experimental work began by reporting Experiment 3.1 in which participants responded with spatial foot responses to the object category (kitchen or garage) of a series of photographs of everyday objects. The location and X-Z orientation of these objects were manipulated. Although task-irrelevant object properties, compatibility effects were nevertheless observed between object location and response, and object orientation and response. Affordance-based explanations of perception-action compatibility effects are intuitive when, for example, a hand is compatible with an object's orientation, or a grip type is compatible with the size of an object. However, it is not obvious how the orientation of an object affords a foot response. These results were therefore discussed in terms of the specificity of actions afforded by visual objects. In particular it was argued that compatible actions might be 'set up' by the physical context of a task (thus considering the influence of action -> perception links in a loop), and furthermore the possibility of visuomotor primitives that are common to many actions was discussed.

Recommendations

In using photographs of real oriented objects, one cannot be sure of the extent to which any orientation-action compatibility effects are associated with the purely visual attributes of orientation, or with the action connotations 'semantically' associated with a functional part of the object (most obviously a handle). This ambiguity was a major motivation for using oriented artificial objects in later experiments (oriented lines and cylinders). These artificial objects had no history of functionally driven interactions. In contrast, the lever's simple mechanics in Experiment 6.3 specified a clear functional end.

There is some evidence to suggest that the functionality of objects does impact on action. For example, Creem and Proffitt (2001b) ran a small series of experiments in which participants had to grasp and pick up a handled object. A handled object (e.g. a hammer, paintbrush, screwdriver etc.) was placed on a table in front of the participant. The object's handle always faced away from the participant, and the object was either placed "vertically" [sic] on the table (the object lay horizontally on the table with its head pointing directly towards, and its handle pointing directly away from, the perceiver-actor's body), or it was rotated 45° to the left or right of 'vertical'. With respect to the participant's dominant hand, the object's handle was classified as either neutral ('vertical'), towards (e.g. 45° to the left of vertical) or away (e.g. 45° to right of vertical). In one experiment, where the task was simply to pick up the object with the dominant hand (control group), 72 % of grasps were appropriate for the object's use (i.e. the handle was grasped in such a way that the object might be used for its correct purpose). When grasps were made with a concurrent 'spatial' task (spatial imagery group), appropriateness of grasp fell to 55 % (statistically, this difference was not significantly different from the control group). However, when grasps were made with a concurrent 'semantic' task (word-pair association group), appropriateness of grasp fell to 17 % (statistically, this difference was significantly different from the control). Furthermore, in all tasks, appropriate grasping came mostly from the "towards" orientation, followed by "neutral" and then "away". Creem and Proffitt (2001b) concluded that without the influence of the cognitive system, the visuomotor system can reach and grasp an object effectively. However, to grasp an object appropriately for its proper use, partial information is needed from the semantic system (which was interfered with in the concurrent semantic task group).

It is of particular interest whether such an interaction between cognition and visuomotor processing might also occur automatically, even without the intention to grasp an object (in a similar way to the APH's claim that that purely visual attributes of an object automatically potentiate aspects of action, regardless of an intention to act). Indeed, in addressing this question a series of experiments that have not been reported were performed as part of this thesis. Unfortunately, the stimuli used had serious confounds that were reflected in the data (see Appendix 6 for example stimuli and brief descriptions).

In light of these failed efforts, the following recommends a potential experiment that uses carefully considered and apparently confound-free stimuli. The experimenter shows participants a model of an object, and demonstrates how it can be used as a bottle stop (by holding the square component to push the cylinder component into a bottle), or as an ink stamp (by holding the cylinder component to push the ink covered square component down onto a piece of paper). The participants then perform a reaction-time study where responses are made to variously oriented pictures of this object (see two example orientations in Figure 7.1). An inter-trial stimulus is shown with the words 'towards me' or 'away from me'. According to the stated direction, upon viewing the oriented object (target stimulus), participants must make a left or right response that classifies the object's identity (e.g. ink stamp = left, bottle stop = right). This classification is based on what function the object would have if it moved in the direction stated. Should object function automatically influence action (regardless of an intention to act), then it might be predicted that the orientation most appropriate for grasping with a particular hand would change depending upon the perceived object identity (and that this might be reflected in RTs and mistakes). Crucially, because the same object is used (albeit with two identities), there are no *visual features* that differ between a stamp and a bottle stop. This proposed experiment would therefore tap into the influence of an object's function without being confounded by its visual features.

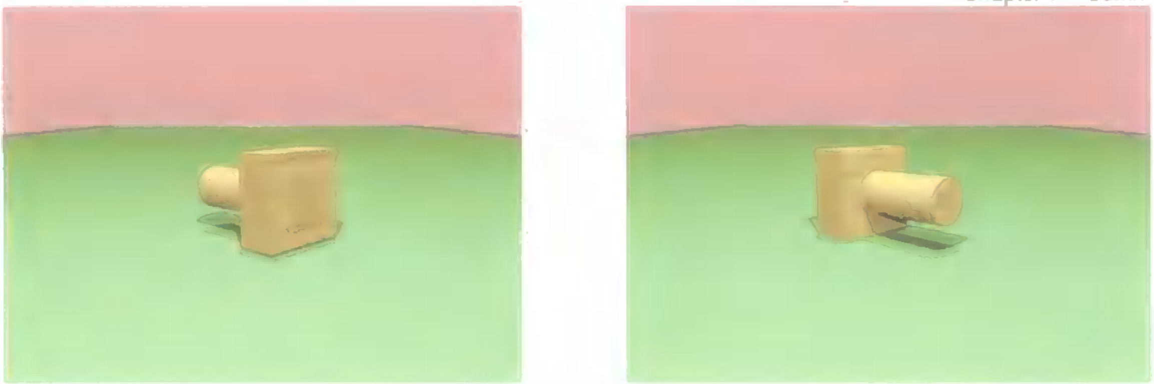


Figure 7.1 Two rightwards orientations of the dual-identity object. Taking the leftmost picture as an example, a 'towards me' direction would make the object an ink stamp (thus affording a left hand reach-to-grasp), and an 'away from me' direction would make the object a bottle stop (thus affording a right hand reach-to-grasp)

7.1.4 Two-dimensional object orientation (Chapter 4)

Having established that photographs of real oriented objects could influence a range of responses, including foot responses (Chapter 3), experimentation now sought to establish what specific *visual properties* of an object's orientation might be (in part) responsible for such effects. Three reaction-time experiments (Experiments 4.1-4.3) were reported that examined the relationship between spatial responses and perhaps the most basic element of orientation, namely the angle of the X-Y axis. Objective 2 was therefore as follows:

Objective 2: To test for orientation-action compatibility effects associated with diagonal two-dimensional lines, thus exploring the possibility that a specific visual attribute might afford left-right actions; namely the angle of an object's X-Y axis. Using these simple stimuli, different left-right response types are used in order to test whether any compatibility effects are specific to hands, or viable for a range of actions.

In Experiment 4.1 line location as well as X-Y line orientation were varied. Both were task-irrelevant properties since responses were based on the colour of the line. While line location produced a straightforward Simon Effect for both hand and foot key presses, X-Y line orientation did not facilitate performance (regardless of the type of response effector). In focussing on X-Y line orientation and hand key presses, efforts were made in the next two experiments (Experiments 4.2 and 4.3) to uncover an effect of X-Y line orientation on compatible responses. Such an effect was not forthcoming, despite making the colour distinction upon which responses were based harder (demanding that more attention was paid to the stimulus), and despite the use of different SOAs (which ensured further control over stimulus viewing times). It was concluded that the X-Y dimension of an oriented 2D line did not present itself as a visual attribute that afforded elements of an action (e.g. spatial hand or foot selection/initiation).

Recommendations

Although the potential influence of 2D line orientation was not pursued further in the experimental work, it is possible that orientation in the X-Z plane (which proved to be the crucial plane for action when using 3D oriented cylinders) might similarly benefit compatible responses, even when using 2D lines. Thus an experiment that used colour classification criteria for making responses might be performed using a 2D line that appeared (thanks to its background) to be oriented in the X-Z plane (see Figure 7.2). Finding that such a stimulus did evoke faster and more accurate compatible responses would have serious implications for the 'attention-directing hypothesis', since there is no visually or functionally salient area of the line.

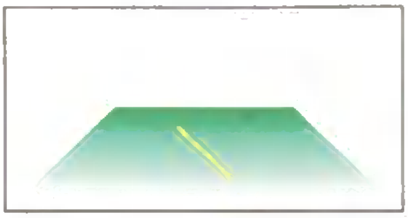


Figure 7.2 A 2D line oriented rightwards in the X-Z plane

7.1.5 Three-dimensional object orientation (Chapter 5)

Having found no orientation-action compatibility effects with 2D lines that were oriented in the X-Y plane (Chapter 4), experimentation turned to 3D stimuli. In continuing to ask what visual properties of an object's orientation might afford components of an action, three further reaction-time experiments (Experiments 5.1-5.3) were reported that used a 3D version of the diagonal line, namely an oriented cylinder. In orienting this cylinder in 3D space, the relative influence of all three planes on responses could be examined. Objective 3 was therefore as follows:

Objective 3: To test for orientation-action compatibility effects associated with computer-generated three-dimensional cylinders that are oriented in three-dimensional space, thus exploring the possibility that a specific visual attribute (i.e. the angle of an object's primary axis within a particular three-dimensional plane) might afford left-right actions. Using these stimuli, different left-right response types are used in order to test whether any compatibility effects are specific to hands, or viable for a range of actions.

As spatial responses were made to the surface pattern of a cylinder, cylinder orientation was task-irrelevant. In all three experiments the only plane that produced a 'pure' orientation-action compatibility effect was the X-Z plane. This occurred for spatial hand key presses, spatial power grips and spatial foot key presses. This finding supported the idea of visuomotor primitives common to a range of actions. In this instance, it was suggested that these visuomotor primitives were activated automatically upon encoding the visual attribute of X-Z cylinder orientation. However, there was a slight trend that suggested this effect was largest for spatial power grips and smallest for spatial foot key presses. This was discussed in terms of spreading activation in a distributed perception-action network and in terms of TEC's 'feature-weighting principle' whereby the different effect sizes observed possibly reflected different activation strengths of the same feature codes. Consistent with all these ideas was the possibility that a physical and intentional preparedness to perform a certain action (i.e. an action with a left-right spatial dimension) had 'set up' attention to select those visual properties of an object that were relevant to that partially prepared action (i.e. the leftward-rightward X-Z cylinder orientation).

Recommendations

In opting for the most ecologically realistic portrayal of an oriented 3D cylinder, the visually salient area at the cylinder's leading edge was accepted as a fact about real objects that theoretically at least, presented itself as an unfortunate confound. Consequently all data relating to the X-Z orientation of a cylinder was open to an alternative attention-directing hypothesis. There is scope however to isolate various properties of this visual saliency, and incrementally remove them[50]. By incrementally removing these properties, the essence of the cylinder would hopefully remain (whereas to remove them all at once, this essence would surely be lost).

[50] Having said this, it is likely that the combination of these 'confounding' features actually describes an object's orientation in 3D space and consequently helps describe significance for action. That attention is directed towards them is presumably an important part of an affordance mechanism, so to remove these features in the name of experimental control somewhat misses the point!

So, as was suggested earlier (see footnote 44, p.183), one could a) artificially manipulate lighting conditions such that each end of the cylinder had the same illumination values, b) artificially shrink the radius of the leading edge of the cylinder such that each end had the same *visual* radius, c) superimpose a disc on the farthest end of the cylinder such that each end of the cylinder had a visible leading edge, and d) artificially shift the cylinder slightly up or down and left or right to remove signs of spatial protraction and retraction. It is possible that removing one of these features would remove the influence of X-Z cylinder orientation on compatible responses.

7.1.6 Perception-action couplings and task context (Chapter 6)

Having demonstrated that the X-Z plane was the crucial dimension from which cylinder orientation exerted its influence on spatial responses (Chapter 5), investigations turned to task context. Could the apparently 'default' relationship between the visual attribute of orientation in the X-Z plane and elements of a left-or-right action (that was observed independently of any object function, and independently of any intention to actually interact with the cylinder), be changed or added to in some way by manipulating the task context? The impetus behind this question came from a theoretical position that supposed action-oriented representations are not fixed and prescribed, but are loosely constrained mechanisms that are adaptable to the context of new perception-action couplings. Objective 4 was therefore as follows:

> **Objective 4:** To develop Objective 3 further by exploring how the orientation-action compatibility effects established in Chapter 5 might be modulated by various task manipulations that include stimulus onset asynchrony, apparent motion and participation in an ongoing dynamic activity

In Experiment 6.1 the same cylinders from Chapter 5 were used, but the time-to-response was manipulated by introducing different SOAs (0, 400 and 800 ms). Again, because spatial responses were based on surface pattern, cylinder orientation was task-irrelevant. In addition to the now familiar effect of X-Z cylinder orientation, it appeared that under the longest delays of 800 ms, responses were faster when they were compatible with a cylinder's X-Y orientation. It was speculated that given time (thanks to the delay), the visuomotor system had 'sought out' new visual features that could be relevant to action.

In Experiment 6.2 the same cylinders were presented in an animation sequence such that they appeared to be moving directly towards the viewer. Again, because spatial responses were based on surface pattern, cylinder orientation was task-irrelevant. This apparent motion had the dramatic effect of wiping out the influence that X-Z cylinder orientation had previously and consistently been shown to have on compatible spatial responses. It was suggested that the 'default' affordance associated with X-Z cylinder orientation had been eradicated or overridden in response to a newfound pressure to withdraw away from the visually looming stimulus.

In Experiment 6.3, similarly oriented cylinders featured as a component in a lever-like device. Spatial responses categorised the movement of the lever according to the length of a previously shown line. On its own the orientation of the cylinder component was task irrelevant. However, it was relevant to the task in its relation with the bar, since an understanding of the simple mechanics of each lever configuration was necessary for determining how it should move. The results showed three particularly interesting effects. Firstly there was an interaction between Y-Z cylinder orientation and bar position. Responses were faster for those levers that would require an upward reach trajectory (were one to physically reach toward the lever). This appeared to be an elaboration of a main effect of Y-Z cylinder orientation from two previous experiments, perhaps reflecting the elaboration of a less reliable 'default' affordance. Secondly, in interacting with X-Z bar position, there was a reversal of the previously established compatibility effect between X-Z cylinder orientation and spatial response. This was interpreted as the modulation of a 'default' affordance. Thirdly there was an interaction between mapping rule, X-Z bar position, Y-Z cylinder orientation and spatial response. This interaction appeared to reflect a graded sensitivity to lever movement difficulties, were one to physically move the lever.

It was argued that this reflected action simulation or motor imagery that was sensitive to biomechanical constraints.

Recommendations

In relation to Experiment 6.1, the onset of new compatibility effects (in particular the interaction between X-Y cylinder orientation and response) could be investigated further by varying SOA's in a more thorough and systematic manner.

In relation to Experiment 6.2, the idea that withdrawal or release responses were afforded needs testing. Participants could make left and right power grip releases, rather than squeezes; or key-press releases (rather than presses). Alternatively, the animation sequence could be played in reverse, such that the cylinder appeared to move away from the viewer, thus taking away the possible influence of visual looming.

In relation to Experiment 6.3, there are a number of follow-up studies that may be revealing. Firstly, the elaboration and modification of 'defaults' deserves some attention. The data that applied to these possibly changed 'defaults' related to *initial* lever configurations (it was collapsed across mapping rule conditions, and consequently across upward and downward lever movements). As the important factor was the initial lever configuration, these changed 'defaults' should be present when visual feedback is removed. While removing feedback addresses the robustness of these changed defaults, it would also ask an important question with regards to those effects that did include mapping rule. Was the visual feedback of an event necessary for the appearance of these effects? Thus the lever experiment could be replicated with the single change of removing visual feedback of lever movements.

Secondly, in asking whether visual feedback of an event was necessary, one might also ask to what extent the whole activity of moving levers was necessary for producing such a range of interesting data. Clearly the high-order interaction that appeared to reflect the use of biomechanically sensitive motor imagery was dependent on having to move a lever upwards or downwards. Nevertheless, with respect to the other results, it would be interesting to see how many remained when the activity aspect of the task was removed. Thus responses could quite simply categorise the surface pattern of the cylinder component of the lever. In this way, orientation and the simple mechanics of the lever would be completely task irrelevant.

Finally, while the high-order interaction irrefutably produced clearly graded effect sizes, its interpretation (that implicated the biomechanical difficulty of actually moving these levers) could be strengthened by some qualification. Thus in much the same way as the Johnson (2000a) studies reported earlier, it would be helpful to have participants rate the difficulty of moving the different levers. One such study might involve rating the physical difficulty/ awkwardness, *were* one to produce the lever movements displayed on the screen (the time taken to rate each movement could also be measured). Another might involve rating the physical difficulty of making real movements of a scaled up working model of the lever (indeed these actual movements could be timed also, and various other measurements might be taken that established the degrees of freedom and forces involved). It might be predicted that these measures would support the interpretation of biomechanical sensitivity, such that those lever movements rated as most difficult or awkward corresponded to those lever movements in Experiment 6.3 that took the longest time to respond to (and similarly for easy movements and short RTs).

General recommendations

Investigating visuomotor processes such as affordance-based mechanisms is no longer a marginalized line of inquiry. In recent years recognition that perception and action are intimately linked processes has ensured that an embodied perspective has become almost mainstream in cognitive science. This embodied perspective will doubtless spurn many different research initiatives, and theories will develop and be rejected. Indeed, very recently a hypothesis has been proposed that questions the now-orthodox dichotomy of the two visual systems. Glover (2003) proposes instead that there is a dichotomy between planning and the on-line control of actions, each of which has a separate visual representation. Whether this hypothesis stands or falls, it has important implications for affordance-based research. Do affordances operate solely in an action-planning domain, or can they influence action control also? With this in mind, it is clear that if the control of actions is to be investigated, binary response measures will not be adequate. More suitable measures might use data gloves and other virtual reality equipment that would allow visual events, actions and sequences of actions to unfold over time.

7.2 Implications for the 'attention-directing hypothesis'

It was noted in the previous chapter (see p.155, footnote 23) that although it was a perfectly symmetrical object centred in 3D space, the oriented cylinder used in Experiments 5.1-6.2 nevertheless had a slightly protracting visually salient circular area at its leading edge (where the cylinder ended). Unavoidably then, the data pertaining to the X-Z plane that was interpreted as reflecting a 'default' affordance for left-right action properties, could equally be interpreted as reflecting the influence of a directing of attention towards this salient area. It has already been argued in Chapter 1 that the directing of attention is but one (albeit important) link in a perception-action loop, and therefore should not hold an explanative monopoly.

Nevertheless, a challenge to the 'attention-directing hypothesis' (e.g. Anderson et al. 2002) would arise if the trend of an orientation-action compatibility effect (e.g. that *could* be attributed to the directing of attention towards a visually salient area) were to actually be *reversed* in accordance with a new affordance for action (e.g. as promoted by a behavioural task that gave the same cylinder a new significance for action). In such a case, the *visually* salient area could not be responsible for the changed compatibility effect. The following points outline some challenges to the attention-directing hypothesis that have arisen from the current work.

1. In Experiment 6.3, result [6.3.9✓] revealed a change of compatibility that reflected a new affordance for action despite an unchanged area of visual salience. In interacting with X-Z bar position, there was a reversal of the previously established compatibility effect between X-Z cylinder orientation and spatial response[51].
2. The intricate pattern present in result [6.3.10✓] broke down into meaningful components only with respect to the difficulty of lever movements (*were* one to actually make them). Such a complex pattern (that was nevertheless wholly interpretable from an action perspective) does not lend itself whatsoever to a simplistic directing of attention account (i.e. neither the visually salient area or the functionally salient area of the cylinder component can explain the graded pattern of these results).
3. In Experiment 6.1, the appearance of a new compatibility effect between X-Y cylinder orientation and hand of response came from those cylinders that were oriented leftwards or rightwards in the X-Y plane. Firstly it will be noted that the cylinder had no functional connotations. Secondly, it will be noted that the two cylinders from which leftwards X-Y orientation was derived (cylinders 2 & 3) had a visually salient area on the left (cylinder 3) or on the right (cylinder 2). Similarly, the two cylinders from which rightwards X-Y orientation was derived (cylinders 1 & 4) had a visually salient area on the left (cylinder 1) or on the right (cylinder 4). Such an interaction between X-Y cylinder orientation and hand of response should not have occurred under an attention-directing account, because the visually salient areas were effectively lost when collapsing the data. Furthermore, there was no functionally salient area.

In conclusion, it appears to be the case that several of the effects found in Chapter 6 might challenge the action-neutral 'attention-directing hypothesis'.

7.3 Concluding remarks

The work of this thesis has tested and developed a hypothesis of visual representation that implicates the motor system (the APH). The experimental work has contributed to this hypothesis by demonstrating that micro-affordances are loosely constrained mechanisms.

[51] Actually, the attention-directing hypothesis would probably argue that rather than visual saliency, there is now functional saliency. However points 2 and 3 are not open to a visual or functional saliency argument.

This finding supports the range of embodied theories and approaches that have been described as the 'middle way'. What is meant by 'loosely constrained' is this: micro-affordances can be described as both specific (a) and general (b). They can be described as representational default settings that remain more-or-less stable (c). However, when intentions, goals or behavioural contexts change, these default settings can change (d).

This claim can be qualified as follows:

a) *Micro-affordances can be specific*

   i. *Visual attribute specificity:* Of the dimensional planes that an object can be oriented in, only one specific isolated plane consistently afforded left-right components of an action (the X-Z plane). In keeping with this specificity, the X-Y orientation of 2D lines did not influence responses, and during standard tasks nor did the X-Y orientation of 3D cylinders.

   ii. *Action specificity:* When motor imagery appeared to have been used, a remarkably specific pattern of interaction was revealed in the RT data that suggested sensitivity to biomechanical constraints.

b) *Micro-affordances can be general*

   i. *Visual attribute generality:* Although specific to the X-Z plane, this orientation's underlying visual attribute was general enough to be gleaned from a variety of quite different objects (kitchen and garage objects, cylinders, levers).

   ii. *Action generality:* When default affordances were observed they influenced left-right components of actions in a general manner. Hence, left-right responses that were facilitated by X-Z object orientation (photographs of real objects and graphically rendered ones) included foot key presses, hand key presses and power grip responses.

c) *Micro-affordances resemble more-or-less stable defaults:* When there was no intention to interact with an object, the affordance associated with orientation in the X-Z plane resembled a more-or-less stable default. Its effect on responses was consistent and reliable, even when time-to-response was manipulated.

d) *These defaults are not fixed or prescribed but adaptable:* However, when the behavioural or task context changed significantly, then new affordances were evoked and default ones were modified, elaborated, eradicated or overridden. For example, a delayed time-to-response allowed the visuomotor system to 'seek out' possibilities in the X-Y plane; apparent motion eradicated the default X-Z affordance, perhaps overriding it with an affordance to withdraw or release; and engaging in a dynamic activity with a lever (in which there was an intention to (virtually) interact with the object) elaborated a possible default associated with the Y-Z plane, modified a default affordance associated with the X-Z plane, and introduced a new and complex affordance that implicated a sensitivity to biomechanical constraints.

The proposed mechanism of micro-affordance is a clear case of an action-oriented representation. The beauty of action-oriented representations is that the hard computational work is taken out of the initial stages of action planning. Motor programs are not developed from scratch, but instead are automatically partially programmed or soft assembled. In being partially programmed or soft assembled, these elemental motor programs are not fixed or prescribed; but are instead *loosely constrained* and therefore eminently adaptable. It would make little sense for autonomous agents like us to have a partial motor program that could not be modified, elaborated, overridden or rejected. If this were the case we would be totally stimulus-driven agents.

The same visuomotor code that is implicated in processing a particular visual feature of an object is also a partially programmed code for action. No translation is necessary from perception to action (or vice-versa), and as such various motor components are automatically activated on viewing an object. Similarly, if proposed accounts of these so-called 'common codes' or 'visuomotor primitives' are correct, then it makes no difference which came first- the stimulus or the response. Thus the same visuomotor code implicated in processing an intention to grasp with a particular hand is also a partially programmed code for a visual feature of an object. This idea does full justice to the workings of a perception-action loop. Perceiving and acting are dynamically intertwined aspects of a single process: perceiving-acting.

8. Appendices

Contents

8.1 Appendix 1 (ANOVA tables)

Table 8.1 Experiment 3.1 (A by P): Repeated measures ANOVA for mean correct responses

Source	SS	DF	MS	F	P
loc	1765.078	1	1765.078	2.018	0.166
loc*MR	50.710	1	50.710	0.058	0.811
error(loc)	24489.856	28	874.638		
ori	9529.632	1	9529.632	11.675	0.002
ori*MR	3.999	1	3.999	0.005	0.945
error(ori)	22854.275	28	816.224		
res	1586.410	1	1586.410	0.334	0.568
res*MR	2631.450	1	2631.450	0.553	0.463
error(res)	133152.409	28	4755.443		
loc* ori	1010.815	1	1010.815	2.004	0.168
loc* ori*MR	94.150	1	94.150	0.187	0.669
error(loc*ori)	14123.420	28	504.408		
loc*res	35797.280	1	35797.280	29.497	0.000
loc*res*MR	200.568	1	200.568	0.165	0.687
error(loc*res)	33980.803	28	1213.600		
ori*res	3380.102	1	3380.102	4.060	0.054
ori*res*MR	2409.074	1	2409.074	2.893	0.100
error(ori*res)	23313.916	28	832.640		
loc* ori*res	1977.889	1	1977.889	2.116	0.157
loc*ori*res*MR	865.640	1	865.640	0.926	0.344
error(loc*ori*res)	26168.695	28	934.596		
Intercept	131148568.460	1	131148568.460	1281.595	0.000
MR	2801.530	1	2801.530	0.027	0.870
error	2865303.743	28	102332.277		

Table 8.2 Experiment 3.1 (A by P): Repeated measures ANOVA for mean incorrect responses

Source	SS	DF	MS	F	P
loc	0.022	1	0.022	0.006	0.940
loc*MR	43.582	1	43.582	11.562	0.002
error(loc)	105.544	28	3.769		
ori	6.220	1	6.220	0.732	0.400
ori*MR	13.451	1	13.451	1.583	0.219
error(ori)	237.948	28	8.498		
res	0.194	1	0.194	0.010	0.922
res*MR	155.497	1	155.497	7.935	0.009
error(res)	548.726	28	19.597		
loc*ori	3.637	1	3.637	0.806	0.377
loc*ori*MR	3.637	1	3.637	0.806	0.377
error(loc*ori)	126.377	28	4.513		
loc*res	246.406	1	246.406	20.351	0.000
loc*res*MR	0.194	1	0.194	0.016	0.900
error(loc*res)	339.015	28	12.108		
ori*res	1.055	1	1.055	0.115	0.737
ori*res*MR	2.604	1	2.604	0.284	0.598
error(ori*res)	256.543	28	9.162		
loc*ori*res	1.055	1	1.055	0.227	0.637
loc*ori*res*MR	0.194	1	0.194	0.042	0.840
error(loc*ori*res)	129.821	28	4.636		
Intercept	2245.373	1	2245.373	80.519	0.000
MR	36.179	1	36.179	1.297	0.264
error	780.820	28	27.886		

Table 8.3 Experiment 3.1 (A by M): Repeated measures ANOVA for mean correct responses

Source	SS	DF	MS	F	P
loc	618.473	1	618.473	.584	.449
loc*MR	1656.997	1	1656.997	1.565	.218
error(loc)	44481.903	42	1059.093		
ori	3724.798	1	3724.798	6.511	.014
ori*MR	569.755	1	569.755	.996	.324
error(ori)	24028.290	42	572.102		
res	255.121	1	255.121	.194	.662
res*MR	20733.191	1	20733.191	15.799	.000
error(res)	55117.063	42	1312.311	55117.063	42
loc*ori	1872.904	1	1872.904	2.019	.163
loc*ori*MR	1205.008	1	1205.008	1.299	.261
error(loc*ori)	38956.799	42	927.543		
loc*res	44806.132	1	44806.132	60.580	.000
loc*res*MR	4.911	1	4.911	.007	.935
error(loc*res)	31064.089	42	739.621935		
ori*res	3129.662	1	3129.662	4.732	.035
ori*res*MR	1027.149	1	1027.149	1.553	.220
error(ori*res)	27776.392	42	661.3431.553		
loc*ori*res	1333.822	1	1333.822	1.573	.217
loc*ori*res*MR	112.508	1	112.508	.133	.717
error(loc*ori*res)	35607.602	42	847.80033		
Intercept	188809963.286	1	188809963.286	11350.900	.000
MR	684.680	1	684.680	.041	.840
error	698624.649	42	16633.920		

Table 8.4 Experiment 3.1 (A by M): Repeated measures ANOVA for mean incorrect responses

Source	SS	DF	MS	F	P
loc	3.157E-02	1	3.157E-02	.005	.944
loc*MR	.284	1	.284	.046	.832
error(loc)	262.184	42	6.242		
ori	9.122	1	9.122	1.212	.277
ori*MR	3.819	1	3.819	.507	.480
error(ori)	316.225	42	7.529		
res	.284	1	.284	.029	.866
res*MR	53.062	1	53.062	5.374	.025
error(res)	414.710	42	9.8745.374		
loc*ori	5.335	1	5.335	1.028	.316
loc*ori*MR	.284	1	.284	.055	.816
error(loc*ori)	217.992	42	5.190		
loc*res	361.395	1	361.395	25.136	.000
loc*res*MR	63.920	1	63.920	4.446	.041
error(loc*res)	603.851	42	14.377		
ori*res	1.547	1	1.547	.147	.703
ori*res*MR	19.729	1	19.729	1.878	.178
error(ori*res)	441.225	42	10.505		
loc*ori*res	1.547	1	1.547	.103	.749
loc*ori*res*MR	5.335	1	5.335	.357	.553
error(loc*ori*res)	627.841	42	14.949		
Intercept	3293.213	1	3293.213	33.900	.000
MR	228.062	1	228.062	2.348	.133
error	4080.114	42	97.146		

Table 8.5 Experiment 3.1 × Experiment 1 of Symes 1999 (A by P): Repeated measures ANOVA for mean correct responses

Source	SS	DF	MS	F	P
loc	1567.753	1	1567.753	2.875	.095
loc*expt	392.842	1	392.842	.721	.400
loc*MR	1.162	1	1.162	.002	.963
loc*expt*MR	124.298	1	124.298	.228	.635
error(loc)	30533.070	56	545.233		
ori	8329.500	1	8329.500	16.876	.000
ori*expt	2189.229	1	2189.229	4.435	.040
ori*MR	121.646	1	121.646	.246	.622
ori*expt*MR	67.260	1	67.260	.136	.713
error(ori)	27640.444	56	493.579		
res	1262.435	1	1262.435	.472	.495
res*expt	432.516	1	432.516	.162	.689
res*MR	2233.703	1	2233.703	.835	.365
res*expt*MR	639.270	1	639.270	.239	.627
error(res)	149866.864	56	2676.194		
loc*ori	3244.072	1	3244.072	8.843	.004
loc*ori*expt	143.861	1	143.861	.392	.534
loc*ori*MR	3.488	1	3.488	.010	.923
loc*ori*expt*MR	243.048	1	243.048	.663	.419
error(loc*ori)	20544.189	56	366.861		
loc*res	38576.036	1	38576.036	45.124	.000
loc*res*expt	5064.282	1	5064.282	5.924	.018
loc*res*MR	70.426	1	70.426	.082	.775
loc*res*expt*MR	807.720	1	807.720	.945	.335
error(loc*res)	47874.341	56	854.899		
ori*res	4041.557	1	4041.557	7.794	.007
ori*res*expt	347.719	1	347.719	.671	.416
ori*res*MR	1137.629	1	1137.629	2.194	.144
ori*res*expt*MR	1273.357	1	1273.357	2.456	.123
error(ori*res)	29037.582	56	518.528		
loc*ori*res	104.776	1	104.776	.169	.683
loc*ori*res*expt	2772.966	1	2772.966	4.473	.039
loc*ori*res*MR	223.696	1	223.696	.361	.550
loc*ori*res*expt*MR	710.339	1	710.339	1.146	.289
error(loc*ori*res)	34712.912	56	619.873		
Intercept	222347827.522	1	222347827.522	3609.612	.000
expt	1649318.253	1	1649318.253	26.775	.000
MR	2296.438	1	2296.438	.037	.848
expt*MR	15073.639	1	15073.639	.245	.623
error	3449533.648	56	61598.815		

Table 8.6 Experiment 4.1 (A by P): Repeated measures ANOVA for mean correct responses

Source	SS	DF	MS	F	P
eff	461781.238	1	461781.238	87.082	0.000
eff*MR1	21673.938	1	21673.938	4.087	0.053
eff*map2	300.575	1	300.575	0.057	0.814
eff*MR1*MR2	2218.500	1	2218.500	0.418	0.523
error(eff)	148479.301	28	5302.832		
loc	10263.600	2	5131.800	21.728	0.000
loc*MR1	304.473	2	152.236	0.645	0.529
loc*MR2	466.381	2	233.191	0.987	0.379
loc*MR1*MR2	245.642	2	122.821	0.520	0.597
error(loc)	13226.456	56	236.187		
x-y ori	120.492	1	120.492	0.593	0.448
x-y ori*MR1	237.897	1	237.897	1.171	0.288
x-y ori*MR2	234.879	1	234.879	1.156	0.291
x-y ori*MR1*MR2	50.287	1	50.287	0.248	0.623
error(x-y ori)	5688.784	28	203.171		
res	2323.805	1	2323.805	2.635	0.116
res*MR1	4627.773	1	4627.773	5.248	0.030
res*MR2	18.976	1	18.976	0.022	0.884
res*MR1*MR2	530.338	1	530.338	0.601	0.445
error(res)	24691.441	28	881.837		
eff*loc	632.214	2	316.107	1.221	0.303
eff*loc*MR1	1199.984	2	599.992	2.318	0.108
eff*loc*MR2	219.979	2	109.989	0.425	0.656
eff*loc*MR1*MR2	443.945	2	221.973	0.858	0.430
error(eff*loc)	14494.866	56	258.837		
eff*x-y ori	5.845	1	5.845	0.029	0.867

Table 8.6 Experiment 4.1 (A by P): Repeated measures ANOVA for mean correct responses (continued)

Source	SS	DF	MS	F	P
eff*x-y ori*MR1	87.750	1	87.750	0.429	0.518
eff*x-y ori*MR2	20.073	1	20.073	0.098	0.757
eff*x-y ori*MR1*MR2	1434.563	1	1434.563	7.007	0.013
error(eff*x-y ori)	5732.905	28	204.747		
loc*x-y ori	253.899	2	126.949	0.664	0.519
loc*x-y ori*MR1	1250.408	2	625.204	3.272	0.045
loc*x-y ori*MR2	172.748	2	86.374	0.452	0.639
loc*x-y ori*MR1*MR2	744.067	2	372.034	1.947	0.152
error(loc*x-y ori)	10699.955	56	191.071		
eff*loc*x-y ori	181.225	2	90.613	0.406	0.668
eff*loc*x-y ori*MR1	350.431	2	175.215	0.785	0.461
eff*loc*x-y ori*MR2	167.317	2	83.658	0.375	0.689
eff*loc*x-y ori*MR1*MR2	704.384	2	352.192	1.578	0.215
error(eff*loc*x-y ori)	12500.535	56	223.224		
eff*res	2404.510	1	2404.510	2.344	0.137
eff*res*MR1	47.442	1	47.442	0.046	0.831
eff*res*MR2	952.746	1	952.746	0.929	0.343
eff*res*MR1*MR2	121.986	1	121.986	0.119	0.733
error(eff*res)	28717.627	28	1025.630		
loc*res	103297.694	2	51648.847	106.070	0.000
loc*res*MR1	354.490	2	177.245	0.364	0.697
loc*res*MR2	420.556	2	210.278	0.432	0.651
loc*res*MR1*MR2	283.636	2	141.818	0.291	0.748
error(loc*res)	27268.068	56	486.930		
eff*loc*res	14056.558	2	7028.279	22.863	0.000
eff*loc*res*MR1	89.324	2	44.662	0.145	0.865
eff*loc*res*MR2	1248.165	2	624.083	2.030	0.141
eff*loc*res*MR1*MR2	180.687	2	90.344	0.294	0.747
error(eff*loc*res)	17214.72873	56	307.4058702		
x-y ori*res	468.281	1	468.281	2.004	0.168
x-y ori*res*MR1	299.126	1	299.126	1.280	0.267
x-y ori*res*MR2	53.288	1	53.288	0.228	0.637
x-y ori*res*MR1*MR2	13.005	1	13.005	0.056	0.815
error(x-y ori*res)	6543.113	28	233.683		
eff*x-y ori*res	52.847	1	52.847	0.309	0.583
eff*x-y ori*res*MR1	260.983	1	260.983	1.527	0.227
eff*x-y ori*res*MR2	130.763	1	130.763	0.765	0.389
eff*x-y ori*res*MR1*MR2	627.022	1	627.022	3.668	0.066
error(eff*x-y ori*res)	4786.522	28	170.947		
loc*x-y ori*res	642.339	2	321.169	1.810	0.173
loc*x-y ori*res*MR1	280.038	2	140.019	0.789	0.459
loc*x-y ori*res*MR2	923.768	2	461.884	2.603	0.083
loc*x-y ori*res*MR1*MR2	27.608	2	13.804	0.078	0.925
error(loc*x-y ori*res)	9935.047	56	177.412		
eff*loc*x-y ori*res	34.007	2	17.004	0.127	0.881
eff*loc*x-y ori*res*MR1	475.786	2	237.893	1.779	0.178
eff*loc*x-y ori*res*MR2	0.964	2	0.482	0.004	0.996
eff*loc*x-y ori*res*MR1*MR2	125.260	2	62.630	0.468	0.628
error(eff*loc*x-y ori*res)	7489.241	56	133.736		
intercept	168109565.046	1	168109565.046	2203.076	0.000
MR1	1197.951	1	1197.951	0.016	0.901
MR2	72340.682	1	72340.682	0.948	0.339
MR1*MR2	32594.024	1	32594.024	0.427	0.519
error	2136588.645	28	76306.737		

Table 8.7 Experiment 4.1 (A by P): Repeated measures ANOVA for mean incorrect responses

Source	SS	DF	MS	F	P
eff	256.724	1	256.724	15.613	.000
eff*MR1	4.431	1	4.431	.269	.608
eff*MR2	10.277	1	10.277	.625	.436
eff*MR1*MR2	.162	1	.162	.010	.922
error(eff)	460.395	28	16.443		
loc	84.124	2	42.062	5.929	.005
loc*MR1	13.491	2	6.745	.951	.393
loc*MR2	3.077	2	1.539	.217	.806
loc*MR1*MR2	12.671	2	6.335	.893	.415
error(loc)	397.300	56	7.095		
x-y ori	24.669	1	24.669	3.474	.073
x-y ori*MR1	6.298	1	6.298	.887	.354

Table 8.7 Experiment 4.1 (A by P): Repeated measures ANOVA for mean incorrect responses (continued)

Source	SS	DF	MS	F	P
x-y ori*MR2	4.045	1	4.045	.570	.457
x-y ori*MR1*MR2	1.321	1	1.321	.186	.670
error(x-y ori)	198.831	28	7.101		
res	6.253	1	6.253	.428	.518
res*MR1	14.230	1	14.230	.974	.332
res*MR2	5.111	1	5.111	.350	.559
res*MR1*MR2	6.508	1	6.508	.446	.510
error(res)	409.005	28	14.607		
eff*loc	19.785	2	9.893	1.625	.206
eff*loc*MR1	6.153	2	3.077	.505	.606
eff*loc*MR2	21.642	2	10.821	1.778	.178
eff*loc*MR1*MR2	.335	2	.168	.028	.973
error(eff*loc)	340.865	56	6.087		
eff*x-y ori	1.247E-02	1	1.247E-02	.001	.970
eff*x-y ori*MR1	14.481	1	14.481	1.649	.210
eff*x-y ori*MR2	3.347	1	3.347	.381	.542
eff*x-y ori*MR1*MR2	5.259	1	5.259	.599	.445
error(eff*x-y ori)	245.899	28	8.782		
loc*x-y ori	60.946	2	30.473	4.339	.018
loc*x-y ori*MR1	22.991	2	11.496	1.637	.204
loc*x-y ori*MR2	2.489	2	1.245	.177	.838
loc*x-y ori*MR1*MR2	17.446	2	8.723	1.242	.297
error(loc*x-y ori)	393.314	56	7.023		
eff*loc*x-y ori	12.283	2	6.142	.810	.450
eff*loc*x-y ori*MR1	11.516	2	5.758	.760	.473
eff*loc*x-y ori*MR2	1.173	2	.587	.077	.926
eff*loc*x-y ori*MR1*MR2	9.831E-02	2	4.915E-02	.006	.994
error(eff*loc*x-y ori)	424.502	56	7.580		
eff*res	6.505E-02	1	6.505E-02	.007	.936
eff*res*MR1	16.558	1	16.558	1.677	.206
eff*res*MR2	.709	1	.709	.072	.791
eff*res*MR1*MR2	26.235	1	26.235	2.657	.114
error(eff*res)	276.448	28	9.873		
loc*res	839.973	2	419.986	27.492	.000
loc*res*MR1	3.116	2	1.558	.102	.903
loc*res*MR2	22.618	2	11.309	.740	.482
loc*res*MR1*MR2	15.060	2	7.530	.493	.613
error(loc*res)	855.479	56	15.276		
eff*loc*res	11.908	2	5.954	.788	.460
eff*loc*res*MR1	20.780	2	10.390	1.376	.261
eff*loc*res*MR2	29.363	2	14.681	1.944	.153
eff*loc*res*MR1*MR2	36.660	2	18.330	2.427	.098
error(eff*loc*res)	422.872	56	7.551		
x-y ori*res	3.813E-02	1	3.813E-02	.004	.951
x-y ori*res*MR1	31.283	1	31.283	3.174	.086
x-y ori*res*MR2	1.227	1	1.227	.125	.727
x-y ori*res*MR1*MR2	10.388	1	10.388	1.054	.313
error(x-y ori*res)	275.930	28	9.855		
eff*x-y ori*res	1.097	1	1.097	.099	.755
eff*x-y ori*res*MR1	.361	1	.361	.033	.858
eff*x-y ori*res*MR2	7.643E-03	1	7.643E-03	.001	.979
eff*x-y ori*res*MR1*MR2	23.828	1	23.828	2.158	.153
error(eff*x-y ori*res)	309.226	28	11.044		
loc*x-y ori*res	7.169	2	3.584	.385	.682
loc*x-y ori*res*MR1	83.768	2	41.884	4.501	.015
loc*x-y ori*res*MR2	9.434	2	4.717	.507	.605
loc*x-y ori*res*MR1*MR2	24.031	2	12.015	1.291	.283
error(loc*x-y ori*res)	521.075	56	9.305		
eff*loc*x-y ori*res	.928	2	.464	.059	.943
eff*loc*x-y ori*res*MR1	15.674	2	7.837	.989	.378
eff*loc*x-y ori*res*MR2	19.916	2	9.958	1.256	.293
eff*loc*x-y ori*res*MR1*MR2	23.020	2	11.510	1.452	.243
error(eff*loc*x-y ori*res)	443.915	56	7.927		
intercept	4547.935	1	4547.935	57.969	.000
MR1	180.486	1	180.486	2.301	.141
MR2	159.513	1	159.513	2.033	.165
MR1*MR2	19.217	1	19.217	.245	.625
error	2196.730	28	78.455		

Table 8.8 Experiment 4.2 (A by P): Repeated measures ANOVA for mean correct responses

Source	SS	DF	MS	F	P
Delay	295.796	1	295.796	1.721	.206
Delay*MR	509.832	1	509.832	2.966	.102
Error (Delay)	3093.630	18	171.868		
x-y ori	121.562	1	121.562	1.318	.266
x-y ori*MR	19.754	1	19.754	.214	.649
Error (x-y ori)	1660.668	18	92.259		
Response	2639.574	1	2639.574	2.115	.163
Response*MR	92.759	1	92.759	.074	.788
Error (Response)	22468.553	18	1248.253		
Delay*x-y ori	69.731	1	69.731	.472	.501
Delay*x-y ori*MR	69.085	1	69.085	.467	.503
Error (Delay*x-y ori)	2661.528	18	147.863		
Delay*Response	58.868	1	58.868	.223	.643
Delay*Response*MR	3653.466	1	3653.466	13.820	.002
Error(Delay*Response)	4758.571	18	264.365		
x-y ori*Response	1104.386	1	1104.386	2.547	.128
x-y ori*Response*MR	3.698	1	3.698	.009	.927
Error(x-y ori*Response)	7805.766	18	433.654		
Delay*x-y ori*Response	39.644	1	39.644	.441	.515
Delay*x-y ori*Response*MR	30.774	1	30.774	.342	.566
Error(Delay*x-y ori*Response)	1618.944	18	89.941		
Intercept	29403530.923	1	29403530.923	1939.000	.000
MR	2538.259	1	2538.259	0.167	.687
Error	272956.907	18	15164.273		

Table 8.9 Experiment 4.2 (A by P): Repeated measures ANOVA for mean incorrect responses

Source	SS	DF	MS	F	P
Delay	57.600	1	57.600	5.589	.030
Delay*MR	4.900	1	4.900	.475	.499
Error (Delay)	185.500	18	10.306		
x-y ori	3.600	1	3.600	.557	.465
x-y ori*MR	8.100	1	8.100	1.254	.278
Error (x-y ori)	116.300	18	6.461254		
Response	4.900	1	4.900	.462	.506
Response*MR	.000	1	.000	.000	1.000
Error (Response)	191.100	18	10.617		
Delay*x-y ori	.400	1	.400	.050	.825
Delay*x-y ori*MR	22.500	1	22.500	2.830	.110
Error (Delay*x-y ori)	143.100	18	7.950		
Delay*Response	16.900	1	16.900	1.314	.267
Delay*Response*MR	1.600	1	1.600	.124	.728
Error(Delay*Response)	231.500	18	12.861		
x-y ori*Response	36.100	1	36.100	2.950	.103
x-y ori*Response*MR	1.600	1	1.600	.131	.722
Error(x-y ori*Response)	220.300	18	12.239		
Delay*x-y ori*Response	2.500	1	2.500	.479	.498
Delay*x-y ori*Response*MR	3.600	1	3.600	.690	.417
Error(Delay*x-y ori*Response)	93.900	18	5.217		
Intercept	2016.400	1	2016.400	56.579	.000
MR	260.100	1	260.100	7.298	.015
Error	641.500	18	35.639		

Table 8.10 Experiment 4.3 (A by P): Repeated measures ANOVA for mean correct responses

Source	SS	DF	MS	F	P
Delay	33743.494	2	16871.747	19.070	.00
Error (Delay)	24771.838	28	884.70		
x-y ori	143.813	1	143.813	.667	.42
Error (x-y ori)	3017.949	14	215.56		
Response	4419.354	1	4419.354	3.847	.07
Error (Response)	16081.581	14	1148.68		
Delay*x-y ori	366.834	2	183.417	1.184	.32
Error (Delay*x-y ori)	4336.027	28	154.85		
Delay*Response	3004.534	2	1502.267	8.896	.00
Error(Delay*Response)	4728.475	28	168.87		
x-y ori*Response	142.646	1	142.646	.522	.48
Error(x-y ori*Response)	3822.206	14	273.01		
Delay*x-y ori*Response	459.644	2	229.822	1.112	.34
Error(Delay*x-y ori*Response)	5786.914	28	206.67		
Intercept	36084589.734	1	36084589.734	1374.327	.00
Error	367586.736	14	26256.19		

Table 8.11 Experiment 4.3 (A by P): Repeated measures ANOVA for mean incorrect responses

Source	SS	DF	MS	F	P
Delay	36.419	2	18.210	4.157	.02
Error (Delay)	122.656	28	4.38		
x-y ori	3.293	1	3.293	1.188	.29
Error (x-y ori)	38.825	14	2.77		
Response	43.510	1	43.510	4.717	.04
Error (Response)	129.140	14	9.22		
Delay*x-y ori	2.463	2	1.231	.252	.77
Error (Delay*x-y ori)	136.782	28	4.88		
Delay*Response	36.663	2	18.331	3.341	.05
Error(Delay*Response)	153.608	28	5.48		
x-y ori*Response	2.376E-0	1	2.376E-0	0.004	0.948
Error(x-y ori*Response)	75.663	14	5.40		
Delay*x-y ori*Response	2.670	2	1.335	.284	.75
Error(Delay*x-y ori*Response)	131.486	28	4.69		
Intercept	752.789	1	752.789	25.089	.00
Error	420.058	14	30.00		

Table 8.12 Experiment 5.1 (A by P): Repeated measures ANOVA for mean correct responses

Source	SS	DF	MS	F	P
x-y [y-z*x-z]	63.483	1	63.483	.250	.623
x-y*MR [y-z*x-z*MR]	647.952	1	647.952	2.547	.128
error(x-y) [error(y-z*x-z)]	4578.444	18	254.358		
x-z [x-y*y-z]	30.440	1	30.440	.152	.701
x-z*MR [x-y*y-z*MR]	192.294	1	192.294	.961	.340
error(x-z) [error(x-y*y-z)]	3601.218	18	200.068		
resp	594.107	1	594.107	1.546	.230
resp*MR	3349.076	1	3349.076	8.717	.009
error(resp)	6915.214	18	384.179		
y-z [x-y*x-z]	27.391	1	27.391	.218	.646
y-z*MR [x-y*x-z*MR]	7.221	1	7.221	.058	.813
error(y-z) [error(x-y*x-z)]	2259.932	18	125.552		
x-y*resp [y-z*x-z*resp]	128.788	1	128.788	1.016	.327
x-y*resp*MR [y-z*x-z*resp*MR]	1.736	1	1.736	.014	.908
error(x-y*resp) [error(y-z*x-z*resp)]	2282.393	18	126.800		
x-z*resp [x-y*y-z*resp]	3122.726	1	3122.726	17.535	.001
x-z*resp*MR [x-y*y-z*resp*MR]	276.572	1	276.572	1.553	.229
error(x-z*resp) [error(x-y*y-z*resp)]	3205.544	18	178.086		
y-z*resp [x-y*x-z*resp]	224.027	1	224.027	1.764	.201
y-z*resp*MR [x-y*x-z*resp*MR]	3.799	1	3.799	.030	.865
error(y-z*resp) [error(x-y*x-z*resp)]	2286.411	18	127.023		
intercept	36145914.948	1	36145914.948	3209.226	.000
MR	27121.802	1	27121.802	2.408	.138
error	202736.248	18	11263.125		

Table 8.13 Experiment 5.1 (A by P): Repeated measures ANOVA for mean incorrect responses

Source	SS	DF	MS	F	P
x-y [y-z*x-z]	11.901	1	11.901	.605	.447
x-y*MR [y-z*x-z*MR]	6.694	1	6.694	.340	.567
error(x-y) [error(y-z*x-z)]	354.132	18	19.674		
x-z [x-y*y-z]	.331	1	.331	.027	.870
x-z*MR [x-y*y-z*MR]	10.000	1	10.000	.830	.374
error(x-z) [error(x-y*y-z)]	216.942	18	12.052		
resp	182.562	1	182.562	8.380	.010
resp*MR	47.603	1	47.603	2.185	.157
error(resp)	392.149	18	21.786		
y-z [x-y*x-z]	2.066	1	2.066	.223	.643
y-z*MR [x-y*x-z*MR]	5.289	1	5.289	.570	.460
error(y-z) [error(x-y*x-z)]	167.025	18	9.279		
x-y*resp [y-z*x-z*resp]	55.868	1	55.868	3.934	.063
x-y*resp*MR [y-z*x-z*resp*MR]	10.000	1	10.000	.704	.412
error(x-y*resp) [error(y-z*x-z*resp)]	255.620	18	14.201		
x-z*resp [x-y*y-z*resp]	145.785	1	145.785	6.511	.020
x-z*resp*MR [x-y*y-z*resp*MR]	13.967	1	13.967	.624	.440
error(x-z*resp) [error(x-y*y-z*resp)]	403.058	18	22.392		
y-z*resp [x-y*x-z*resp]	2.066	1	2.066	.081	.779
y-z*resp*MR [x-y*x-z*resp*MR]	1.322	1	1.322	.052	.822
error(y-z*resp) [error(x-y*x-z*resp)]	456.942	18	25.386		
intercept	9274.793	1	9274.793	735.902	.000
MR	8.264	1	8.264	.656	.429
error	226.860	18	12.603		

Table 8.14 Experiment 5.2 (A by P): Repeated measures ANOVA for mean correct responses

Source	SS	DF	MS	F	P
x-y [y-z*x-z]	3.679	1	3.679	.042	.840
x-y*MR [y-z*x-z*MR]	9.853	1	9.853	.112	.741
error(x-y) [error(y-z*x-z)]	1577.041	18	87.613		
x-z [x-y*y-z]	261.825	1	261.825	2.580	.126
x-z*MR [x-y*y-z*MR]	438.873	1	438.873	4.325	.052
error(x-z) [error(x-y*y-z)]	1826.490	18	101.472		
resp	233.121	1	233.121	.369	.551
resp*MR	183.047	1	183.047	.290	.597
error(resp)	11356.508	18	630.917		
y-z [x-y*x-z]	15.324	1	15.324	.115	.739
y-z*MR [x-y*x-z*MR]	11.761	1	11.761	.088	.770
error(y-z) [error(x-y*x-z)]	2406.099	18	133.672		
x-y*resp [y-z*x-z*resp]	101.045	1	101.045	.483	.496
x-y*resp*MR [y-z*x-z*resp*MR]	6.617	1	6.617	.032	.861
error(x-y*resp) [error(y-z*x-z*resp)]	3765.369	18	209.187		
x-z*resp [x-y*y-z*resp]	6938.937	1	6938.937	45.509	.000
x-z*resp*MR [x-y*y-z*resp*MR]	122.849	1	122.849	.806	.381
error(x-z*resp) [error(x-y*y-z*resp)]	2744.519	18	152.473		
y-z*resp [x-y*x-z*resp]	13.314	1	13.314	.106	.748
y-z*resp*MR [x-y*x-z*resp*MR]	393.618	1	393.618	3.144	.093
error(y-z*resp) [error(x-y*x-z*resp)]	2253.236	18	125.180		
intercept	38451864.632	1	38451864.632	2834.423	.000
MR	3764.275	1	3764.275	.277	.605
error	244188.521	18	13566.029		

Table 8.15 Experiment 5.2 (A by P): Repeated measures ANOVA for mean incorrect responses

Source	SS	DF	MS	F	P
x-y [y-z*x-z]	57.600	1	57.600	13.042	.002
x-y*MR [y-z*x-z*MR]	.900	1	.900	.204	.657
error(x-y) [error(y-z*x-z)]	79.500	18	4.417		
x-z [x-y*y-z]	12.100	1	12.100	1.419	.249
x-z*MR [x-y*y-z*MR]	48.400	1	48.400	5.676	.028
error(x-z) [error(x-y*y-z)]	153.500	18	8.528		
resp	67.600	1	67.600	5.646	.029
resp*MR	16.900	1	16.900	1.412	.250
error(resp)	215.500	18	11.972		
y-z [x-y*x-z]	2.500	1	2.500	.251	.622
y-z*MR [x-y*x-z*MR]	14.400	1	14.400	1.447	.245
error(y-z) [error(x-y*x-z)]	179.100	18	9.950		
x-y*resp [y-z*x-z*resp]	40.000	1	40.000	3.057	.097
x-y*resp*MR [y-z*x-z*resp*MR]	22.500	1	22.500	1.720	.206
error(x-y*resp) [error(y-z*x-z*resp)]	235.500	18	13.083		
x-z*resp [x-y*y-z*resp]	96.100	1	96.100	8.995	.008
x-z*resp*MR [x-y*y-z*resp*MR]	57.600	1	57.600	5.392	.032
error(x-z*resp) [error(x-y*y-z*resp)]	192.300	18	10.683		
y-z*resp [x-y*x-z*resp]	8.100	1	8.100	.548	.469
y-z*resp*MR [x-y*x-z*resp*MR]	10.000	1	10.000	.677	.421
error(y-z*resp) [error(x-y*x-z*resp)]	265.900	18	14.772		
intercept	4928.400	1	4928.400	219.854	.000
MR	44.100	1	44.100	1.967	.178
error	403.500	18	22.417		

Table 8.16 Experiment 5.1*5.2 (A by P): Repeated measures ANOVA for mean correct responses

Source	SS	DF	MS	F	P
x-y [y-z*x-z]	18.299	1	18.299	.107	.745
x-y*MR [y-z*x-z*MR]	408.803	1	408.803	2.391	.131
x-y*expt [y-z*x-z*expt]	48.862	1	48.862	.286	.596
x-y*MR*expt [y-z*x-z*MR*expt]	249.002	1	249.002	1.456	.235
error(x-y) [error(y-z*x-z)]	6155.485	36	170.986		
x-z [x-y*y-z]	56.858	1	56.858	.377	.543
x-z*MR [x-y*y-z*MR]	606.087	1	606.087	4.020	.053
x-z*expt [x-y*y-z*expt]	235.408	1	235.408	1.561	.220
x-z*MR*expt [x-y*y-z*MR*expt]	25.079	1	25.079	.166	.686
error(x-z) [error(x-y*y-z)]	5427.707	36	150.770		
resp	41.460	1	41.460	.082	.777
resp*MR	2549.031	1	2549.031	5.022	.031
resp*expt	785.768	1	785.768	1.548	.221
resp*MR*expt	983.093	1	983.093	1.937	.173
error(resp)	18271.723	36	507.548		
y-z [x-y*x-z]	41.844	1	41.844	.323	.573
y-z*MR [x-y*x-z*MR]	18.706	1	18.706	.144	.706
y-z*expt [x-y*x-z*expt]	.870	1	.870	.007	.935
y-z*MR*expt [x-y*x-z*MR*expt]	.275	1	.275	.002	.963
error(y-z) [error(x-y*x-z)]	4666.031	36	129.612		
x-y*resp [y-z*x-z*resp]	228.993	1	228.993	1.363	.251
x-y*resp*MR [y-z*x-z*resp*MR]	7.566	1	7.566	.045	.833
x-y*resp*expt [y-z*x-z*resp*expt]	.840	1	.840	.005	.944
x-y*resp*MR*expt [y-z*x-z*resp*MR*expt]	.787	1	.787	.005	.946
error(x-y*resp) [error(y-z*x-z*resp)]	6047.761	36	167.993		
x-z*resp [x-y*y-z*resp]	9685.765	1	9685.765	58.602	.000
x-z*resp*MR [x-y*y-z*resp*MR]	384.037	1	384.037	2.324	.136
x-z*resp*expt [x-y*y-z*resp*expt]	375.899	1	375.899	2.274	.140
x-z*resp*MR*expt [x-y*y-z*resp*MR*expt]	15.383	1	15.383	.093	.762
error(x-z*resp) [error(x-y*y-z*resp)]	5950.062	36	165.280		
y-z*resp [x-y*x-z*resp]	173.285	1	173.285	1.374	.249
y-z*resp*MR [x-y*x-z*resp*MR]	160.040	1	160.040	1.269	.267
y-z*resp*expt [x-y*x-z*resp*expt]	64.056	1	64.056	.508	.481
y-z*resp*MR*expt [x-y*x-z*resp*MR*expt]	237.376	1	237.376	1.882	.179
error(y-z*resp) [error(x-y*x-z*resp)]	4539.647	36	126.101		
intercept	74579955.072	1	74579955.072	6007.450	.000
MR	5338.885	1	5338.885	.430	.516
expt	17824.508	1	17824.508	1.436	.239
MR*expt	25547.193	1	25547.193	2.058	.160
error	446924.769	36	12414.577		

Table 8.17 Experiment 5.1*5.2 (A by P): Repeated measures ANOVA for mean incorrect responses

Source	SS	DF	MS	F	P
x-y [y-z*x-z]	8.569	1	8.569	.711	.405
x-y*MR [y-z*x-z*MR]	6.252	1	6.252	.519	.476
x-y*expt [y-z*x-z*expt]	60.932	1	60.932	5.059	.031
x-y*MR*expt [y-z*x-z*MR*expt]	1.343	1	1.343	.111	.740
error(x-y) [error(y-z*x-z)]	433.632	36	12.045		
x-z [x-y*y-z]	8.215	1	8.215	.798	.378
x-z*MR [x-y*y-z*MR]	7.200	1	7.200	.700	.408
x-z*expt [x-y*y-z*expt]	4.215	1	4.215	.410	.526
x-z*MR*expt [x-y*y-z*MR*expt]	51.200	1	51.200	4.976	.032
error(x-z) [error(x-y*y-z)]	370.442	36	10.290		
resp	236.172	1	236.172	13.992	.001
resp*MR	3.888	1	3.888	.230	.634
resp*expt	13.990	1	13.990	.829	.369
resp*MR*expt	60.615	1	60.615	3.591	.066
error(resp)	607.649	36	16.879		
y-z [x-y*x-z]	4.556	1	4.556	.474	.496
y-z*MR [x-y*x-z*MR]	1.117	1	1.117	.116	.735
y-z*expt [x-y*x-z*expt]	1.033E-02	1	1.033E-02	.001	.974
y-z*MR*expt [x-y*x-z*MR*expt]	18.572	1	18.572	1.932	.173
error(y-z) [error(x-y*x-z)]	346.125	36	9.615		
x-y*resp [y-z*x-z*resp]	95.207	1	95.207	6.979	.012
x-y*resp*MR [y-z*x-z*resp*MR]	1.250	1	1.250	.092	.764
x-y*resp*expt [y-z*x-z*resp*expt]	.661	1	.661	.048	.827
x-y*resp*MR*expt [y-z*x-z*resp*MR*expt]	31.250	1	31.250	2.291	.139
error(x-y*resp) [error(y-z*x-z*resp)]	491.120	36	13.642		
x-z*resp [x-y*y-z*resp]	239.306	1	239.306	14.470	.001
x-z*resp*MR [x-y*y-z*resp*MR]	7.420	1	7.420	.449	.507
x-z*resp*expt [x-y*y-z*resp*expt]	2.579	1	2.579	.156	.695
x-z*resp*MR*expt [x-y*y-z*resp*MR*expt]	64.147	1	64.147	3.879	.057
error(x-z*resp) [error(x-y*y-z*resp)]	595.358	36	16.538		
y-z*resp [x-y*x-z*resp]	9.174	1	9.174	.457	.503
y-z*resp*MR [x-y*x-z*resp*MR]	9.298	1	9.298	.463	.501
y-z*resp*expt [x-y*x-z*resp*expt]	.992	1	.992	.049	.825
y-z*resp*MR*expt [x-y*x-z*resp*MR*expt]	2.025	1	2.025	.101	.753
error(y-z*resp) [error(x-y*x-z*resp)]	722.842	36	20.079		
intercept	13862.506	1	13862.506	791.691	.000
MR	7.091	1	7.091	.405	.529
expt	340.688	1	340.688	19.457	.000
MR*expt	45.273	1	45.273	2.586	.117
error	630.360	36	17.510		

Table 8.18 Experiment 5.3 (A by P): Repeated measures ANOVA for mean correct responses

Source	SS	DF	MS	F	P
eff	203558.649	1	203558.649	63.274	.000
eff*MR1	1405.160	1	1405.160	.437	.518
eff*MR2	34119.072	1	34119.072	10.606	.005
eff*MR1*MR2	2608.763	1	2608.763	.811	.381
error(eff)	51473.380	16	3217.086		
x-y [y-z*x-z]	90.169	1	90.169	.535	.475
x-y*MR1 [y-z*x-z*MR1]	58.480	1	58.480	.347	.564
x-y*MR2 [y-z*x-z*MR2]	79.641	1	79.641	.473	.501
x-y*MR1*MR2 [y-z*x-z*MR1*MR2]	36.048	1	36.048	.214	.650
error(x-y) [error(y-z*x-z)]	2694.143	16	168.384		
x-z [x-y*y-z]	1434.325	1	1434.325	5.651	.030
x-z*MR1 [x-y*y-z*MR1]	239.546	1	239.546	.944	.346
x-z*MR2 [x-y*y-z*MR2]	1.113	1	1.113	.004	.948
x-z*MR1*MR2 [x-y*y-z*MR1*MR2]	1.543	1	1.543	.006	.939
error(x-z) [error(x-y*y-z)]	4061.285	16	253.830		
resp	5603.351	1	5603.351	5.296	.035
resp*MR1	1636.280	1	1636.280	1.546	.232
resp*MR2	1725.966	1	1725.966	1.631	.220
resp*MR1*MR2	1380.072	1	1380.072	1.304	.270
error(resp)	16929.079	16	1058.067		
eff*x-y [eff*y-z*x-z]	5.651	1	5.651	.025	.876
eff*x-y*MR1 [eff*y-z*x-z*MR1]	183.583	1	183.583	.820	.379
eff*x-y*MR2 [eff*y-z*x-z*MR2]	178.736	1	178.736	.798	.385
eff*x-y*MR1*MR2 [eff*y-z*x-z*MR1*MR2]	24.299	1	24.299	.108	.746
error(eff*x-y) [error(eff*y-z*x-z)]	3583.997	16	224.000		
eff*x-z [eff*x-y*y-z]	233.566	1	233.566	.543	.472
eff*x-z*MR1 [eff*x-y*y-z*MR1]	647.934	1	647.934	1.505	.238
eff*x-z*MR2 [eff*x-y*y-z*MR2]	110.973	1	110.973	.258	.619
eff*x-z*MR1*MR2 [eff*x-y*y-z*MR1*MR2]	227.139	1	227.139	.528	.478
error(eff*x-z) [error(eff*x-y*y-z)]	6887.463	16	430.466		
y-z [x-y*x-z]	816.831	1	816.831	4.928	.041
y-z*MR1 [x-y*x-z*MR1]	330.776	1	330.776	1.996	.177
y-z*MR2 [x-y*x-z*MR2]	318.061	1	318.061	1.919	.185
y-z*MR1*MR2 [x-y*x-z*MR1*MR2]	10.749	1	10.749	.065	.802
error(x-z) [error(x-y*x-z)]	2651.974	16	165.748		
eff*y-z [eff*x-y*x-z]	54.410	1	54.410	.326	.576
eff*y-z*MR1 [eff*x-y*x-z*MR1]	103.788	1	103.788	.622	.442
eff*y-z*MR2 [eff*x-y*x-z*MR2]	139.632	1	139.632	.837	.374
eff*y-z*MR1*MR2 [eff*x-y*x-z*MR1*MR2]	4.242	1	4.242	.025	.875
error(eff*y-z) [error(eff*x-y*x-z)]	2667.891	16	166.743		
eff*resp	6572.105	1	6572.105	12.324	.003
eff*resp*MR1	329.240	1	329.240	.617	.443
eff*resp*MR2	89.287	1	89.287	.167	.688
eff*resp*MR1*MR2	192.179	1	192.179	.360	.557
error(eff*resp)	8532.386	16	533.274		
x-y*resp [y-z*x-z*resp]	23.316	1	23.316	.057	.815
x-y*resp*MR1 [y-z*x-z*resp*MR1]	159.656	1	159.656	.388	.542
x-y*resp*MR2 [y-z*x-z*resp*MR2]	56.651	1	56.651	.138	.715
x-y*resp*MR1*MR2 [y-z*x-z*resp*MR1*MR2]	47.704	1	47.704	.116	.738
error(x-y*resp) [error(y-z*x-z*resp)]	6582.797	16	411.425		
eff*x-y*resp [eff*y-z*x-z*resp]	88.213	1	88.213	.449	.512
eff*x-y*resp*MR1 [eff*y-z*x-z*resp*MR1]	1883.444	1	1883.444	9.596	.007
eff*x-y*resp*MR2 [eff*y-z*x-z*resp*MR2]	.298	1	.298	.002	.969
eff*x-y*resp*MR1*MR2 [eff*y-z*x-z*resp*MR1*MR2]	895.421	1	895.421	4.562	.048
error(eff*x-y*resp) [error(eff*y-z*x-z*resp)]	3140.538	16	196.284		
x-z*resp [x-y*y-z*resp]	8818.808	1	8818.808	36.011	.000
x-z*resp*MR1 [x-y*y-z*resp*MR1]	97.800	1	97.800	.399	.536
x-z*resp*MR2 [x-y*y-z*resp*MR2]	253.677	1	253.677	1.036	.324
x-z*resp*MR1*MR2 [x-y*y-z*resp*MR1*MR2]	5.022	1	5.022	.021	.888
error(x-z*resp) [error(x-y*y-z*resp)]	3918.231	16	244.889		
eff*x-z*resp [eff*x-y*y-z*resp]	413.228	1	413.228	1.438	.248
eff*x-z*resp*MR1 [eff*x-y*y-z*resp*MR1]	843.887	1	843.887	2.936	.106
eff*x-z*resp*MR2 [eff*x-y*y-z*resp*MR2]	4.584	1	4.584	.016	.901
eff*x-z*resp*MR1*MR2 [eff*x-y*y-z*resp*MR1*MR2]	127.496	1	127.496	.444	.515

Table 8.18 Experiment 5.3 (A by P): Repeated measures ANOVA for mean correct responses (continued)

Source	SS	DF	MS	F	P
error(eff*x-z*resp) [error(eff*x-y*y-z*resp)]	4598.189	16	287.387		
y-z*resp [x-y*x-z*resp]	748.702	1	748.702	2.526	.132
y-z*resp*MR1 [x-y*x-z*resp*MR1]	10.068	1	10.068	.034	.856
y-z*resp*MR2 [x-y*x-z*resp*MR2]	20.711	1	20.711	.070	.795
y-z*resp*MR1*MR2 [x-y*x-z*resp*MR1*MR2]	67.209	1	67.209	.227	.640
error(y-z*resp) [error(x-y*x-z*resp)]	4741.791	16	296.362		
eff*y-z*resp [eff*x-y*x-z*resp]	154.174	1	154.174	.821	.378
eff*y-z*resp*MR1 [eff*x-y*x-z*resp*MR1]	236.515	1	236.515	1.260	.278
eff*y-z*resp*MR2 [eff*x-y*x-z*resp*MR2]	755.519	1	755.519	4.024	.062
eff*y-z*resp*MR1*MR2 [eff*x-y*x-z*resp*MR1*MR2]	573.484	1	573.484	3.054	.100
error(eff*y-z*resp) [error(eff*x-y*x-z*resp)]	3004.401	16	187.775		
Intercept	81945961.020	1	81945961.020	2452.655	.000
MR1	42630.773	1	42630.773	1.276	.275
MR2	45594.533	1	45594.533	1.365	.260
MR1*MR2	1196.327	1	1196.327	.036	.852
error	534577.982	16	33411.124		

Table 8.19 Experiment 5.3 (A by P): Repeated measures ANOVA for mean incorrect responses

Source	SS	DF	MS	F	P
eff	2.778	1	2.778	.251	.624
eff*MR1	.255	1	.255	.023	.881
eff*MR2	20.570	1	20.570	1.855	.192
eff*MR1*MR2	.892	1	.892	.080	.780
error(eff)	177.388	16	11.087		
x-y [y-z*x-z]	.419	1	.419	.022	.883
x-y*MR1 [y-z*x-z*MR1]	7.710	1	7.710	.409	.532
x-y*MR2 [y-z*x-z*MR2]	.555	1	.555	.029	.866
x-y*MR1*MR2 [y-z*x-z*MR1*MR2]	1.306	1	1.306	.069	.796
error(x-y) [error(y-z*x-z)]	301.910	16	18.869		
x-z [x-y*y-z]	.340	1	.340	.017	.898
x-z*MR1 [x-y*y-z*MR1]	33.190	1	33.190	1.652	.217
x-z*MR2 [x-y*y-z*MR2]	19.567	1	19.567	.974	.338
x-z*MR1*MR2 [x-y*y-z*MR1*MR2]	2.524	1	2.524	.126	.728
error(x-z) [error(x-y*y-z)]	321.393	16	20.087		
resp	222.384	1	222.384	10.117	.006
resp*MR1	34.862	1	34.862	1.586	.226
resp*MR2	42.713	1	42.713	1.943	.182
resp*MR1*MR2	27.586	1	27.586	1.255	.279
error(resp)	351.687	16	21.980		
eff*x-y [eff*y-z*x-z]	.635	1	.635	.023	.881
eff*x-y*MR1 [eff*y-z*x-z*MR1]	10.961	1	10.961	.401	.536
eff*x-y*MR2 [eff*y-z*x-z*MR2]	11.902	1	11.902	.435	.519
eff*x-y*MR1*MR2 [eff*y-z*x-z*MR1*MR2]	1.503	1	1.503	.055	.818
error(eff*x-y) [error(eff*y-z*x-z)]	437.519	16	27.345		
eff*x-z [eff*x-y*y-z]	.233	1	.233	.028	.868
eff*x-z*MR1 [eff*x-y*y-z*MR1]	.845	1	.845	.103	.753
eff*x-z*MR2 [eff*x-y*y-z*MR2]	3.732	1	3.732	.454	.510
eff*x-z*MR1*MR2 [eff*x-y*y-z*MR1*MR2]	4.621	1	4.621	.562	.464
error(eff*x-z) [error(eff*x-y*y-z)]	131.658	16	8.229		
y-z [x-y*x-z]	50.411	1	50.411	5.972	.027
y-z*MR1 [x-y*x-z*MR1]	9.934	1	9.934	1.177	.294
y-z*MR2 [x-y*x-z*MR2]	5.264	1	5.264	.624	.441
y-z*MR1*MR2 [x-y*x-z*MR1*MR2]	40.508	1	40.508	4.799	.044
error(x-z) [error(x-y*x-z)]	135.063	16	8.441		
eff*y-z [eff*x-y*x-z]	.699	1	.699	.047	.832
eff*y-z*MR1 [eff*x-y*x-z*MR1]	9.892	1	9.892	.659	.429
eff*y-z*MR2 [eff*x-y*x-z*MR2]	3.299	1	3.299	.220	.645
eff*y-z*MR1*MR2 [eff*x-y*x-z*MR1*MR2]	.322	1	.322	.021	.885
error(eff*y-z) [error(eff*x-y*x-z)]	240.015	16	15.001		
eff*resp	44.535	1	44.535	2.558	.129
eff*resp*MR1	23.706	1	23.706	1.362	.260
eff*resp*MR2	10.101	1	10.101	.580	.457
eff*resp*MR1*MR2	5.917	1	5.917	.340	.568
error(eff*resp)	278.535	16	17.408		
x-y*resp [y-z*x-z*resp]	11.893	1	11.893	1.043	.322

Table 8.19 Experiment 5.3 (A by P): Repeated measures ANOVA for mean incorrect responses (continued)

Source	SS	DF	MS	F	P
x-y*resp*MR1 [y-z*x-z*resp*MR1]	12.595	1	12.595	1.105	.309
x-y*resp*MR2 [y-z*x-z*resp*MR2]	1.490	1	1.490	.131	.722
x-y*resp*MR1*MR2 [y-z*x-z*resp*MR1*MR2]	1.009	1	1.009	.088	.770
error(x-y*resp) [error(y-z*x-z*resp)]	182.412	16	11.401		
eff*x-y*resp [eff*y-z*x-z*resp]	2.253	1	2.253	.161	.693
eff*x-y*resp*MR1 [eff*y-z*x-z*resp*MR1]	41.577	1	41.577	2.975	.104
eff*x-y*resp*MR2 [eff*y-z*x-z*resp*MR2]	3.185	1	3.185	.228	.640
eff*x-y*resp*MR1*MR2 [eff*y-z*x-z*resp*MR1*MR2]	7.956	1	7.956	.569	.462
error(eff*x-y*resp) [error(eff*y-z*x-z*resp)]	223.605	16	13.975		
x-z*resp [x-y*y-z*resp]	300.835	1	300.835	14.632	.001
x-z*resp*MR1 [x-y*y-z*resp*MR1]	.530	1	.530	.026	.874
x-z*resp*MR2 [x-y*y-z*resp*MR2]	18.774	1	18.774	.913	.353
x-z*resp*MR1*MR2 [x-y*y-z*resp*MR1*MR2]	1.530	1	1.530	.074	.788
error(x-z*resp) [error(x-y*y-z*resp)]	328.956	16	20.560		
eff*x-z*resp [eff*x-y*y-z*resp]	120.230	1	120.230	8.771	.009
eff*x-z*resp*MR1 [eff*x-y*y-z*resp*MR1]	1.558	1	1.558	.114	.740
eff*x-z*resp*MR2 [eff*x-y*y-z*resp*MR2]	10.895	1	10.895	.795	.386
eff*x-z*resp*MR1*MR2 [eff*x-y*y-z*resp*MR1*MR2]	90.719	1	90.719	6.618	.020
error(eff*x-z*resp) [error(eff*x-y*y-z*resp)]	219.321	16	13.708		
y-z*resp [x-y*x-z*resp]	14.757	1	14.757	.534	.475
y-z*resp*MR1 [x-y*x-z*resp*MR1]	5.504	1	5.504	.199	.661
y-z*resp*MR2 [x-y*x-z*resp*MR2]	21.944	1	21.944	.794	.386
y-z*resp*MR1*MR2 [x-y*x-z*resp*MR1*MR2]	57.605	1	57.605	2.085	.168
error(y-z*resp) [error(x-y*x-z*resp)]	441.996	16	27.625		
eff*y-z*resp [eff*x-y*x-z*resp]	32.450	1	32.450	3.668	.074
eff*y-z*resp*MR1 [eff*x-y*x-z*resp*MR1]	25.567	1	25.567	2.890	.108
eff*y-z*resp*MR2 [eff*x-y*x-z*resp*MR2]	8.352	1	8.352	.944	.346
eff*y-z*resp*MR1*MR2 [eff*x-y*x-z*resp*MR1*MR2]	33.501	1	33.501	3.787	.069
error(eff*y-z*resp) [error(eff*x-y*x-z*resp)]	141.553	16	8.847		
Intercept	11208.611	1	11208.611	95.793	.000
MR1	307.495	1	307.495	2.628	.125
MR2	3.796	1	3.796	.032	.859
MR1*MR2	60.097	1	60.097	.514	.484
error	1872.146	16	117.009		

Table 8.20 Experiment 6.1 (A by P): Repeated measures ANOVA for mean correct responses

Source	SS	DF	MS	F	P
delay	251507.442	2	125753.721	101.585	.000
delay*MR	15351.940	2	7675.970	6.201	.005
error(delay)	44565.054	36	1237.918		
x-y [y-z*x-z]	1044.791	1	1044.791	4.747	.043
x-y*MR [y-z*x-z*MR]	4.126E-05	1	4.126E-05	.000	1.000
error(x-y) [error(y-z*x-z)]	3961.989	18	220.110		
x-z [x-y*y-z]	180.239	1	180.239	.863	.365
x-z*MR [x-y*y-z*MR]	.813	1	.813	.004	.951
error(x-z) [error(x-y*y-z)]	3757.809	18	208.767		
resp	964.534	1	964.534	.588	.453
resp*MR	1.363	1	1.363	.001	.977
error(resp)	29539.855	18	1641.103		
delay*x-y [delay*y-z*x-z]	493.618	2	246.809	.673	.516
delay*x-y*MR [delay*y-z*x-z*MR]	165.411	2	82.706	.226	.799
error(delay*x-y) [error(delay*y-z*x-z)]	13193.852	36	366.496		
delay*x-z [delay*x-y*y-z]	939.308	2	469.654	1.531	.230
delay*x-z*MR [delay*x-y*y-z*MR]	57.466	2	28.733	.094	.911
error(delay*x-z) [error(delay*x-y*y-z)]	11047.020	36	306.862		
y-z [x-y*x-z]	514.531	1	514.531	3.157	.092
y-z*MR [x-y*x-z*MR]	82.394	1	82.394	.506	.486
error(y-z) [error(x-y*x-z)]	2933.509	18	162.973		
delay*y-z [delay*x-y*x-z]	155.173	2	77.587	.371	.693
delay*y-z*MR [delay*x-y*x-z*MR]	682.766	2	341.383	1.632	.210
error(delay*y-z) [error(delay*x-y*x-z)]	7530.655	36	209.185		
delay*resp	187.665	2	93.832	.248	.782
delay*resp*MR	2326.181	2	1163.090	3.071	.059
error(delay*resp)	13634.578	36	378.738		
x-y*resp [y-z*x-z*resp]	1637.430	1	1637.430	6.990	.017
x-y*resp*MR [y-z*x-z*resp*MR]	679.658	1	679.658	2.901	.106
error(x-y*resp) [error(y-z*x-z*resp)]	4216.615	18	234.256		
delay*x-y*resp [delay*y-z*x-z*resp]	1681.144	2	840.572	3.005	.062
delay*x-y*resp*MR [delay*y-z*x-z*resp*MR]	949.412	2	474.706	1.697	.198
error(delay*x-y*resp) [error(delay*y-z*x-z*resp)]	10069.019	36	279.695		
x-z*resp [x-y*y-z*resp]	7388.927	1	7388.927	52.785	.000
x-z*resp*MR [x-y*y-z*resp*MR]	17.260	1	17.260	.123	.730
error(x-z*resp) [error(x-y*y-z*resp)]	2519.669	18	139.982		
delay*x-z*resp [delay*x-y*y-z*resp]	178.378	2	89.189	.363	.698
delay*x-z*resp*MR [delay*x-y*y-z*resp*MR]	1175.783	2	587.892	2.395	.106
error(delay*x-z*resp) [error(delay*x-y*y-z*resp)]	8837.325	36	245.481		
y-z*resp [x-y*x-z*resp]	25.734	1	25.734	.120	.733
y-z*resp*MR [x-y*x-z*resp*MR]	81.042	1	81.042	.379	.546
error(y-z*resp) [error(x-y*x-z*resp)]	3851.548	18	213.975		
delay*y-z*resp [delay*x-y*x-z*resp]	53.319	2	26.659	.106	.899
delay*y-z*resp*MR [delay*x-y*x-z*resp*MR]	1383.019	2	691.509	2.761	.077
error(delay* y-z*resp) [error(delay*x-y*x-z*resp)]	9015.308	36	250.425		
intercept	115645303.924	1	115645303.924	1678.955	.000
MR	6756.878	1	6756.878	.098	.758
error	1239828.170	18	68879.343		

Table 8.21 Experiment 6.1 (A by P): Repeated measures ANOVA for mean incorrect responses

Source	SS	DF	MS	F	P
delay	20.867	2	10.433	.491	.616
delay*MR	12.200	2	6.100	.287	.752
error(delay)	764.267	36	21.230		
x-y [y-z*x-z]	3.333E-02	1	3.333E-02	.001	.970
x-y*MR [y-z*x-z*MR]	.833	1	.833	.037	.849
error(x-y) [error(y-z*x-z)]	402.467	18	22.359		
x-z [x-y*y-z]	32.033	1	32.033	2.567	.127
x-z*MR [x-y*y-z*MR]	56.033	1	56.033	4.491	.048
error(x-z) [error(x-y*y-z)]	224.600	18	12.478		
resp	149.633	1	149.633	5.415	.032
resp*MR	177.633	1	177.633	6.428	.021
error(resp)	497.400	18	27.633		
delay*x-y [delay*y-z*x-z]	82.067	2	41.033	2.234	.122
delay*x-y*MR [delay*y-z*x-z*MR]	3.267	2	1.633	.089	.915
error(delay*x-y) [error(delay*y-z*x-z)]	661.333	36	18.370		
delay*x-z [delay*x-y*y-z]	5.267	2	2.633	.101	.904
delay*x-z*MR [delay*x-y*y-z*MR]	10.467	2	5.233	.200	.820
error(delay*x-z) [error(delay*x-y*y-z)]	941.600	36	26.156		
y-z [x-y*x-z]	12.033	1	12.033	.840	.372
y-z*MR [x-y*x-z*MR]	2.700	1	2.700	.188	.669
error(y-z) [error(x-y*x-z)]	257.933	18	14.330		
delay*y-z [delay*x-y*x-z]	11.267	2	5.633	.422	.659
delay*y-z*MR [delay*x-y*x-z*MR]	9.800	2	4.900	.367	.695
error(delay*y-z) [error(delay*x-y*x-z)]	480.267	36	13.341		
delay*resp	14.867	2	7.433	.436	.650
delay*resp*MR	48.067	2	24.033	1.408	.258
error(delay*resp)	614.400	36	17.067		
x-y*resp [y-z*x-z*resp]	14.700	1	14.700	1.159	.296
x-y*resp*MR [y-z*x-z*resp*MR]	24.300	1	24.300	1.916	.183
error(x-y*resp) [error(y-z*x-z*resp)]	228.333	18	12.685		
delay*x-y*resp [delay*y-z*x-z*resp]	111.800	2	55.900	2.829	.072
delay*x-y*resp*MR [delay*y-z*x-z*resp*MR]	43.400	2	21.700	1.098	.344
error(delay*x-y*resp) [error(delay*y-z*x-z*resp)]	711.467	36	19.763		
x-z*resp [x-y*y-z*resp]	168.033	1	168.033	5.115	.036
x-z*resp*MR [x-y*y-z*resp*MR]	4.033	1	4.033	.123	.730
error(x-z*resp) [error(x-y*y-z*resp)]	591.267	18	32.848		
delay*x-z*resp [delay*x-y*y-z*resp]	16.067	2	8.033	.655	.525
delay*x-z*resp*MR [delay*x-y*y-z*resp*MR]	1.267	2	.633	.052	.950
error(delay*x-z*resp) [error(delay*x-y*y-z*resp)]	441.333	36	12.259		
y-z*resp [x-y*x-z*resp]	14.700	1	14.700	.761	.395
y-z*resp*MR [x-y*x-z*resp*MR]	40.833	1	40.833	2.113	.163
error(y-z*resp) [error(x-y*x-z*resp)]	347.800	18	19.322		
delay*y-z*resp [delay*x-y*x-z*resp]	225.800	2	112.900	5.331	.009
delay*y-z*resp*MR [delay*x-y*x-z*resp*MR]	22.467	2	11.233	.530	.593
error(delay* y-z*resp) [error(delay*x-y*x-z*resp)]	762.400	36	21.178		
intercept	7905.633	1	7905.633	51.808	.000
MR	36.300	1	36.300	.238	.632
error	2746.733	18	152.596		

Table 8.22 Experiment 6.2 (A by P): Repeated measures ANOVA for mean correct responses

Source	SS	DF	MS	F	P
x-y [y-z*x-z]	218.498	1	218.498	1.022	.325
x-y*MR [y-z*x-z*MR]	3.438E-05	1	3.438E-05	.000	1.000
error(x-y) [error(y-z*x-z)]	3846.582	18	213.699		
x-z [x-y*y-z]	39.810	1	39.810	.114	.740
x-z*MR [x-y*y-z*MR]	183.946	1	183.946	.527	.477
error(x-z) [error(x-y*y-z)]	6284.753	18	349.153		
resp	29551.125	1	29551.125	33.266	.000
resp*MR	33.255	1	33.255	.037	.849
error(resp)	15989.882	18	888.327		
y-z [x-y*x-z]	1390.545	1	1390.545	5.846	.026
y-z*MR [x-y*x-z*MR]	2.609E-03	1	2.609E-03	.000	.997
error(y-z) [error(x-y*x-z)]	4281.270	18	237.848		
x-y*resp [y-z*x-z*resp]	10.342	1	10.342	.039	.846
x-y*resp*MR [y-z*x-z*resp*MR]	199.354	1	199.354	.749	.398
error(x-y*resp) [error(y-z*x-z*resp)]	4792.369	18	266.243		
x-z*resp [x-y*y-z*resp]	256.187	1	256.187	1.004	.330
x-z*resp*MR [x-y*y-z*resp*MR]	985.134	1	985.134	3.859	.065
error(x-z*resp) [error(x-y*y-z*resp)]	4594.937	18	255.274		
y-z*resp [x-y*x-z*resp]	244.857	1	244.857	.579	.457
y-z*resp*MR [x-y*x-z*resp*MR]	500.065	1	500.065	1.182	.291
error(y-z*resp) [error(x-y*x-z*resp)]	7614.864	18	423.048		
intercept	56615893.290	1	56615893.290	2672.025	.000
MR	698.225	1	698.225	.033	.858
error	381390.893	18	21188.383		

Table 8.23 Experiment 6.3 (A by P): Repeated measures ANOVA for mean incorrect responses

Source	SS	DF	MS	F	P
x-y [y-z*x-z]	85.069	1	85.069	19.794	.000
x-y*MR [y-z*x-z*MR]	66.736	1	66.736	15.528	.001
error(x-y) [error(y-z*x-z)]	77.361	18	4.298		
x-z [x-y*y-z]	3.403	1	3.403	.339	.568
x-z*MR [x-y*y-z*MR]	11.736	1	11.736	1.169	.294
error(x-z) [error(x-y*y-z)]	180.694	18	10.039		
resp	140.625	1	140.625	5.737	.028
resp*MR	25.069	1	25.069	1.023	.325
error(resp)	441.250	18	24.514		
y-z [x-y*x-z]	8.403	1	8.403	.630	.438
y-z*MR [x-y*x-z*MR]	25.069	1	25.069	1.879	.187
error(y-z) [error(x-y*x-z)]	240.139	18	13.341		
x-y*resp [y-z*x-z*resp]	20.069	1	20.069	.863	.365
x-y*resp*MR [y-z*x-z*resp*MR]	1.736	1	1.736	.075	.788
error(x-y*resp) [error(y-z*x-z*resp)]	418.472	18	23.248		
x-z*resp [x-y*y-z*resp]	1.736	1	1.736	.115	.738
x-z*resp*MR [x-y*y-z*resp*MR]	6.944E-02	1	6.944E-02	.005	.947
error(x-z*resp) [error(x-y*y-z*resp)]	271.806	18	15.100		
y-z*resp [x-y*x-z*resp]	1.736	1	1.736	.153	.701
y-z*resp*MR [x-y*x-z*resp*MR]	.625	1	.625	.055	.817
error(y-z*resp) [error(x-y*x-z*resp)]	204.583	18	11.366		
intercept	4100.625	1	4100.625	41.412	.000
MR	390.625	1	390.625	3.945	.062
error	1782.361	18	99.020		

Table 8.24 Experiment 6.3 (A by P): Repeated measures ANOVA for mean correct responses

Source	SS	DF	MS	F	P
bar	44314.289	1	44314.289	37.983	.000
bar*MR	192.188	1	192.188	.165	.690
error(bar)	21000.355	18	1166.686		
x-y [y-z*x-z]	963.020	1	963.020	2.566	.127
x-y*MR [y-z*x-z*MR]	207.471	1	207.471	.553	.467
error(x-y) [error(y-z*x-z)]	6756.071	18	375.337		
x-z [x-y*y-z]	443.367	1	443.367	.894	.357
x-z*MR [x-y*y-z*MR]	61.527	1	61.527	.124	.729
error(x-z) [error(x-y*y-z)]	8928.116	18	496.006		
res	26626.196	1	26626.196	14.656	.001
res*MR	131.784	1	131.784	.073	.791
error(res)	32700.713	18	1816.706		
bar*x-y [bar*y-z*x-z]	281.843	1	281.843	.749	.398
bar*x-y*MR [bar*y-z*x-z*MR]	3720.544	1	3720.544	9.882	.006
error(bar*x-y) [error(bar*y-z*x-z)]	6777.160	18	376.509		
bar*x-z [bar*x-y*y-z]	22.088	1	22.088	.042	.840
bar*x-z*MR [bar*x-y*y-z*MR]	3157.971	1	3157.971	5.994	.025
error(bar*x-z) [error(bar*x-y*y-z)]	9483.025	18	526.835		
x-y*x-z [y-z]	.131	1	.131	.000	.988
x-y*x-z*MR [y-z*MR]	60.328	1	60.328	.104	.751
error(x-y*x-z) [error(y-z)]	10456.340	18	580.908		
bar*x-y*x-z [bar*y-z]	6949.597	1	6949.597	4.093	.058
bar*x-y*x-z*MR [bar*y-z*MR]	150.644	1	150.644	.089	.769
error(bar*x-y*x-z) [error(bar*y-z)]	30564.449	18	1698.025		
bar*res	60.546	1	60.546	.181	.676
bar*res*MR	853.622	1	853.622	2.551	.128
error(bar*res)	6023.824	18	334.657		
x-y*res [y-z*x-z*res]	68.906	1	68.906	.135	.718
x-y*res*MR [y-z*x-z*res*MR]	2207.498	1	2207.498	4.310	.052
error(x-y*res) [error(y-z*x-z*res)]	9219.046	18	512.169		
bar*x-y*res [bar*y-z*x-z*res]	.452	1	.452	.002	.963
bar*x-y*res*MR [bar*y-z*x-z*res*MR]	283.820	1	283.820	1.359	.259
error(bar*x-y*res) [error(bar*y-z*x-z*res)]	3759.667	18	208.870		
x-z*res [x-y*y-z*res]	220.303	1	220.303	.522	.479
x-z*res*MR [x-y*y-z*res*MR]	321.714	1	321.714	.763	.394
error(x-z*res) [error(x-y*y-z*res)]	7592.032	18	421.780		
bar*x-z*res [bar*x-y*y-z*res]	4282.513	1	4282.513	12.570	.002
bar*x-z*res*MR [bar*x-y*y-z*res*MR]	176.419	1	176.419	.518	.481
error(bar*x-z*res) [error(bar*x-y*y-z*res]	6132.615	18	340.701		
x-y*x-z*res [y-z*res]	341.907	1	341.907	.443	.514
x-y*x-z*res*MR [y-z*res*MR]	1699.786	1	1699.786	2.203	.155
error(x-y*x-z*res) [error(y-z*res)]	13887.356	18	771.520		
bar*x-y*x-z*res [bar*y-z*res]	453.045	1	453.045	.076	.786
bar*x-y*x-z*res*MR [bar*y-z*res*MR]	105978.688	1	105978.688	17.683	.001
error(bar*x-y*x-z*res) [error(bar*y-z*res)]	107877.813	18	5993.212		
Intercept	87389398.922	1	87389398.922	3092.712	.000
MR	118478.043	1	118478.043	4.193	.055
error	508618.093	18	28256.561		

Table 8.25 Experiment 6.3 (A by P): Repeated measures ANOVA for mean incorrect responses

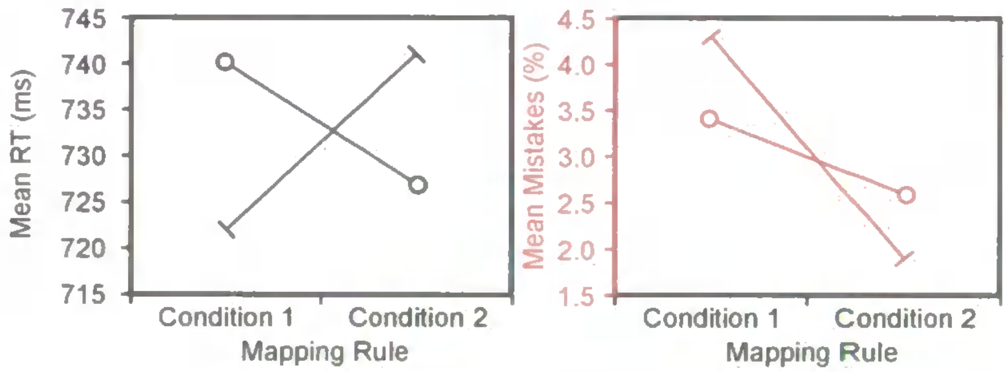
Source	SS	DF	MS	F	P
bar	27.222	1	27.222	1.956	.179
bar*MR	.000	1	.000	.000	1.000
error(bar)	250.556	18	13.920		
x-y [y-z*x-z]	23.472	1	23.472	2.110	.164
x-y*MR [y-z*x-z*MR]	6.806	1	6.806	.612	.444
error(x-y) [error(y-z*x-z)]	200.278	18	11.127		
x-z [x-y*y-z]	2.222	1	2.222	.161	.693
x-z*MR [x-y*y-z*MR]	.000	1	.000	.000	1.000
error(x-z) [error(x-y*y-z)]	247.778	18	13.765		
res	73.472	1	73.472	4.834	.041
res*MR	50.139	1	50.139	3.298	.086
error(res)	273.611	18	15.201		
bar*x-y [bar*y-z*x-z]	8.889	1	8.889	.489	.493
bar*x-y*MR [bar*y-z*x-z*MR]	13.889	1	13.889	.764	.394
error(bar*x-y) [error(bar*y-z*x-z)]	327.222	18	18.179		
bar*x-z [bar*x-y*y-z]	.139	1	.139	.005	.943
bar*x-z*MR [bar*x-y*y-z*MR]	170.139	1	170.139	6.347	.021
error(bar*x-z) [error(bar*x-y*y-z)]	482.500	18	26.806		
x-y*x-z [y-z]	.556	1	.556	.026	.873
x-y*x-z*MR [y-z*MR]	27.222	1	27.222	1.297	.270
error(x-y*x-z) [error(y-z)]	377.778	18	20.988		
bar*x-y*x-z [bar*y-z]	11.250	1	11.250	.378	.546
bar*x-y*x-z*MR [bar*y-z*MR]	61.250	1	61.250	2.058	.169
error(bar*x-y*x-z) [error(bar*y-z)]	535.833	18	29.769		
bar*res	2.222	1	2.222	.138	.714
bar*res*MR	8.889	1	8.889	.554	.466
error(bar*res)	288.889	18	16.049		
x-y*res [y-z*x-z*res]	40.139	1	40.139	2.651	.121
x-y*res*MR [y-z*x-z*res*MR]	23.472	1	23.472	1.550	.229
error(x-y*res) [error(y-z*x-z*res)]	272.500	18	15.139		
bar*x-y*res [bar*y-z*x-z*res]	.556	1	.556	.041	.843
bar*x-y*res*MR [bar*y-z*x-z*res*MR]	13.889	1	13.889	1.014	.327
error(bar*x-y*res) [error(bar*y-z*x-z*res)]	246.667	18	13.704		
x-z*res [x-y*y-z*res]	2.222	1	2.222	.236	.633
x-z*res*MR [x-y*y-z*res*MR]	45.000	1	45.000	4.780	.042
error(x-z*res) [error(x-y*y-z*res)]	169.444	18	9.414		
bar*x-z*res [bar*x-y*y-z*res]	256.806	1	256.806	15.060	.001
bar*x-z*res*MR [bar*x-y*y-z*res*MR]	16.806	1	16.806	.986	.334
error(bar*x-z*res) [error(bar*x-y*y-z*res]	306.944	18	17.052		
x-y*x-z*res [y-z*res]	13.889	1	13.889	.448	.512
x-y*x-z*res*MR [y-z*res*MR]	.000	1	.000	.000	1.000
error(x-y*x-z*res) [error(y-z*res)]	558.333	18	31.019		
bar*x-y*x-z*res [bar*y-z*res]	11.250	1	11.250	1.028	.324
bar*x-y*x-z*res*MR [bar*y-z*res*MR]	516.806	1	516.806	47.234	.000
error(bar*x-y*x-z*res) [error(bar*y-z*res)]	196.944	18	10.941		
Intercept	7670.139	1	7670.139	96.454	.000
MR	1.250	1	1.250	.016	.902
error	1431.389	18	79.522		

8.2 Appendix 2 (Additional experimental data)

8.2.1 Experiment 3.1

Two-Way Interactions [3.1.2]

In the A by M, there was a significant interaction between mapping rule and foot of response in both RTs [F (1, 42) = 15.799, $p < 0.001$] and mistakes [F (1, 42) = 5.374, $p < 0.05$] (see Figure 8.1). For participants in MR: C1 (kitchen/left, garage/right), mean RTs were 18 ms faster for right (garage objects) rather than left (kitchen objects) foot responses. For participants in MR: C2 (garage/left, kitchen/right), mean RTs were 14 ms faster for left (garage objects) rather than right (kitchen objects) foot responses. This pattern was reversed in the frequency of mistakes. For participants in MR: C1, mean mistakes were 0.9 % fewer for left (kitchen objects) rather than right (garage objects) foot responses. For participants in MR: C2, mean mistakes were 0.7 % fewer for right (kitchen objects) rather than left (garage objects) foot responses. This suggested a speed/accuracy trade-off whereby garage objects were responded to faster at the cost of more mistakes for kitchen objects.



KEY

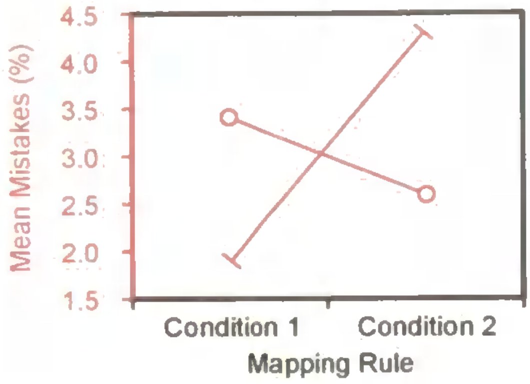
Left response
Right response

MEANS TABLE

MR	Resp	ms	SE	%	SE
1	L	740	10	3.4	0.8
1	R	722	10	4.3	0.8
2	L	727	10	2.6	0.8
2	R	741	10	1.9	0.8

Figure 8.1 (A by M) Mean RTs (black lines) and mean mistakes (red lines) as a function of foot of response and mapping rule

In the A by P, there was also a significant interaction between mapping rule and foot of response in mistakes [F (1, 28) = 7.935, $p < 0.01$] but not in RTs [F (1, 28) = 0.553, $p >$ 0.1] (see Figure 8.2).



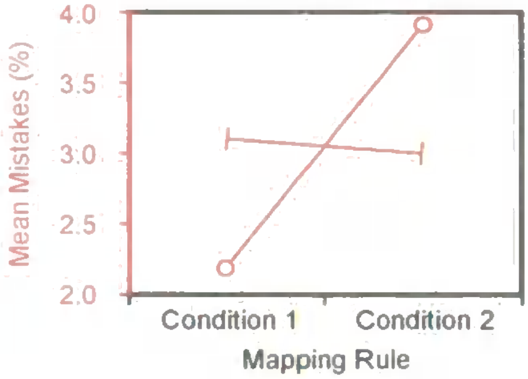
MR	Resp	%	SE
1	L	3.4	0.6
1	R	1.9	0.7
2	L	2.6	0.6
2	R	4.3	0.7

Figure 8.2 (A by P) Mean mistakes as a function of foot of response and mapping rule

For participants in MR: C1, mean mistakes were 1.5 % fewer for right (garage objects) rather than left (kitchen objects) foot responses. For participants in MR: C2, mean mistakes were 1.7 % fewer for left (garage objects) rather than right (kitchen objects) foot responses. This suggested that fewer mistakes were made when responding to garage rather than kitchen objects.

Two-Way Interactions [3.1.3]

In the A by P, there was a significant interaction between mapping rule and object location in mistakes [F (1, 28) = 11.562, $p < 0.005$] but not in RTs [F (1, 28) = 0.058, $p > 0.5$] (see Figure 8.3). For participants in MR: C1, mean mistakes were 0.9 % fewer for left rather than right located objects. For participants in MR: C2, mean mistakes were 0.9 % fewer for right rather than left located objects.



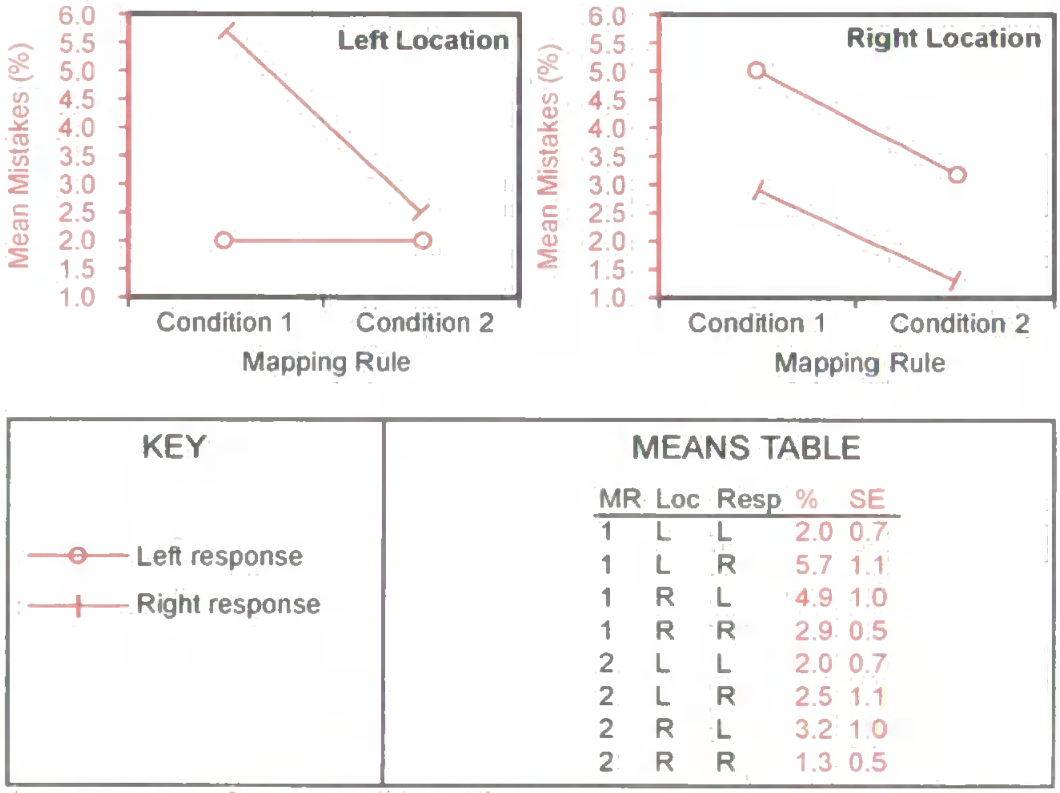
MEANS TABLE

MR	Loc	%	SE
1	L	2.2	0.5
1	R	3.1	0.5
2	L	3.9	0.5
2	R	3.0	0.5

Figure 8.3 (A by P) Mean mistakes as a function of object location and mapping rule

Three-Way Interactions [3.1.6]

In the A by M, there was a significant interaction between mapping rule, foot of response and object location in mistakes [F (1, 42) = 4.446, p < 0.05] but not in RTs [F (1, 42) = 0.007, p > 0.5] (see Figure 8.4).



MEANS TABLE

MR	Loc	Resp	%	SE
1	L	L	2.0	0.7
1	L	R	5.7	1.1
1	R	L	4.9	1.0
1	R	R	2.9	0.5
2	L	L	2.0	0.7
2	L	R	2.5	1.1
2	R	L	3.2	1.0
2	R	R	1.3	0.5

Figure 8.4 (A by M) Mean mistakes as a function of object location, foot of response and mapping rule

For left located objects the following pattern was observed: For participants in MR: C1, mean mistakes were 3.7 % fewer for left rather than right foot responses. For participants in MR: C2, mean mistakes were 0.5 % fewer for left rather than right foot responses. For right located objects the following pattern was observed: For participants in MR: C1, mean mistakes were 2 % fewer for right rather than left foot responses. For participants in MR: C2, mean mistakes were 1.9 % fewer for right rather than left foot responses.

8.2.2 Experiment 4.1

Main Effects [4.1.1]

There was a significant main effect for line location in both RTs [F (2, 56) = 21.728, $p<$ 0.001] and mistakes [F (2, 56) = 5.929, p = 0.005]. Centrally located lines produced the fastest mean RTs (463 ms, SE = 10) and the fewest mean mistakes (2.0 %, SE = 0.3). This reflected the ease of the location-response 'compatibility neutral' trials. Left located lines took on average 471 ms (SE = 10) with 2.8 % mistakes (SE = 0.3), and right located lines took on average 470 ms (SE = 10) with 2.4 % mistakes (SE = 0.4).

Main Effects [4.1.2]

There was a significant main effect of effector in both RTs [F (1, 28) = 87.082, $p<$ 0.001] and mistakes [F (1, 28) = 15.613, p < 0.01]. Mean RTs were 49 ms faster for hand (443 ms, SE = 9) rather than foot (492 ms, SE = 11) responses. Mean mistakes were 1.1 % fewer for foot (1.9 %, SE = 0.3) rather than hand (3.0 %, SE = 0.4) responses. This suggested a speed/accuracy trade-off whereby hand responses were faster at the cost of more mistakes.

Two-Way Interactions [4.1.3]

A result related to the main effect of effector reported above was the interaction between mapping rule 1 and effector. This interaction approached significance in RTs [F (1, 28) = 4.087, p= 0.053] but not in mistakes [F (1, 28) = 0.269, p> 0.5] (see Figure 8.5).

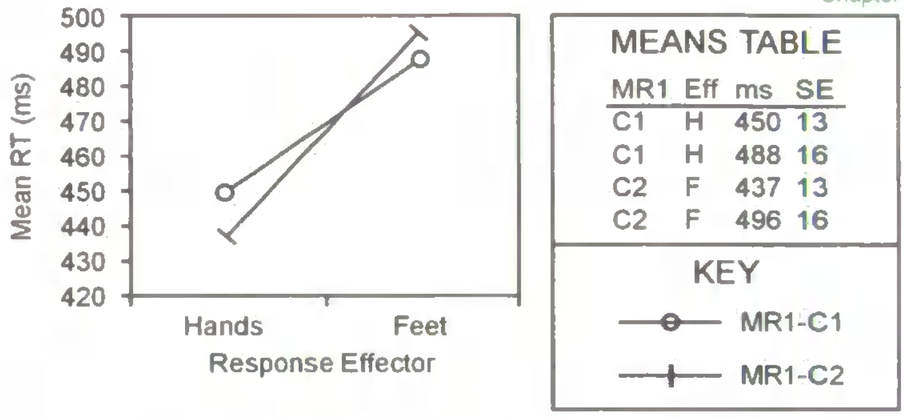


Figure 8.5 Mean RTs as a function of mapping rule 1 and response effector.

The difference between mean RTs for effector type was more pronounced at MR1: C2. For participants in MR1: C2 (feet first, hands second), mean RTs were 59 ms faster for hand rather than foot responses. For participants in MR1: C1 (hands first, feet second), mean RTs were a smaller 38 ms faster for hand rather than foot responses.

Two-Way Interactions [4.1.5]

There was a significant interaction between line location and X-Y line orientation in mistakes [F (2, 56) = 4.339, $p < 0.05$] but not in RTs [F (1, 28) = 0.664, $p > 0.5$] (see Figure 8.6). For lines oriented leftwards in the X-Y plane, mean mistakes were similar when they were located left or right, and faster when located centrally. However, for lines oriented rightwards in the X-Y plane, mean mistakes were fewest when located right, then centrally, and greatest when located left.

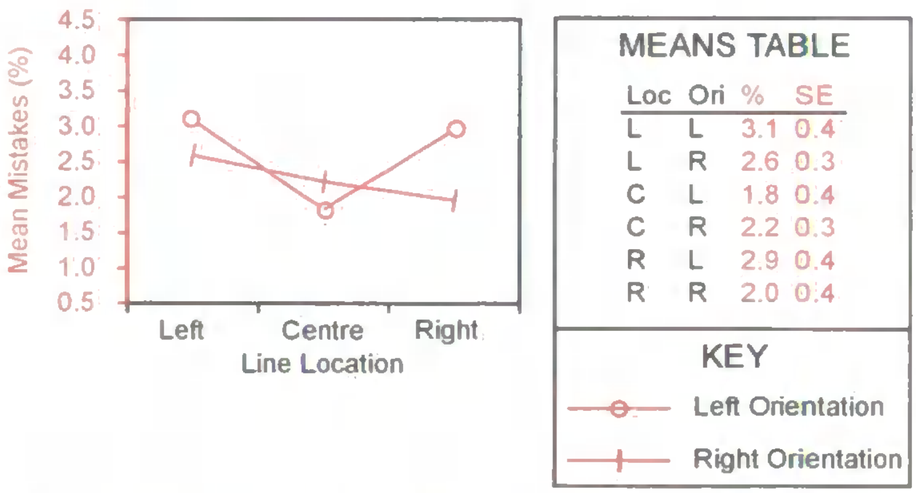
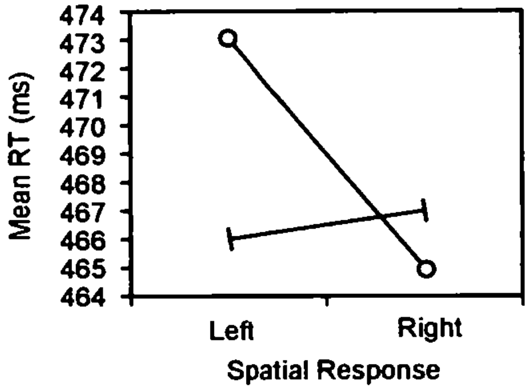


Figure 8.6 Mean mistakes as a function of line location and X-Y line orientation

Two-Way Interactions [4.1.6]

There was a significant interaction between spatial response and mapping rule 1 in RTs [F (1, 28) = 5.248, $p < 0.05$] but not in mistakes [F (1, 28) = 0.974, $p > 0.1$] (see Figure 8.7). For participants in <u>MR1: C1</u> (hands first, feet second), mean RTs were 8 ms faster for right rather than left spatial responses. For participants in <u>MR1: C2</u> (feet first, hands second), mean RTs were similar for both spatial responses (1 ms faster for left rather than right spatial responses).



MEANS TABLE

MR1	Res	ms	SE
C1	L	473	14
C1	R	465	14
C2	L	466	14
C2	R	467	14

KEY

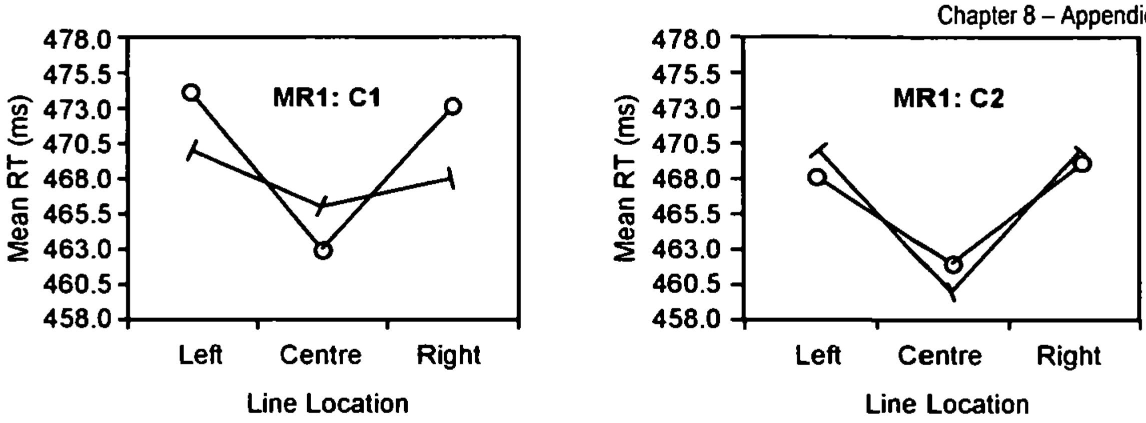
—o— MR1-C1

—+— MR1-C2

Figure 8.7 Mean RTs as a function of mapping rule 1 and spatial response.

Three-Way Interactions [4.1.9]

There was a significant interaction between line location, X-Y line orientation and mapping rule 1 in RTs, [F (2, 56) = 4.272, $p < 0.05$] but not in mistakes [F (2, 56) = 1.637, $p > 0.1$]. In part this appeared to reflect the main effect of line location reported earlier, where centrally located lines were responded to 7-8 ms faster than left and right located lines (note faster RTs at the central line location in Figure 8.8). This difference however, was noticeably less for rightwards-oriented lines under MR1: C1, when compared to the other three conditions.



KEY	MEANS TABLE												
—o— Left Orientation	MR	C1	C1	C1	C1	C1	C1	C2	C2	C2	C2	C2	C2
—+— Right Orientation	Loc	L	L	C	C	R	R	L	L	C	C	R	R
	Ori	L	R	L	R	L	R	L	R	L	R	L	R
	ms	474	470	463	466	473	468	468	470	462	460	469	470
	SE	14	13	14	15	14	14	14	13	14	15	14	14

Figure 8.8 Mean RTs as a function of X-Y line orientation, line location and mapping rule.

Higher Order Interactions [4.1.13]

There was a significant interaction between effector type, X-Y line orientation, mapping rule 1 and mapping rule 2 in RTs, [F (1, 28) = 7.007, $p < 0.05$] but not in mistakes [F (1, 28) = 0.599, $p > 0.1$].

Higher Order Interactions [4.1.14]

There was a significant interaction between line location, X-Y line orientation, spatial response and mapping rule 1 for mistakes, [F (2, 56) = 4.501, $p < 0.05$], but not for RTs [F (2, 56) = 1.779, $p > 0.1$]. Means and standard errors for higher order interactions[1] [4.1.13 & 4.1.14] are located in Appendix 3.

8.2.3 Experiment 4.2

Main Effects [4.2.1]

There was a significant main effect of mapping rule in mistakes, [F (1, 18) = 7.298, $p <$ 0.05] but not in RTs [F (1, 18) = 0.167, $p > 0.5$]. Mean mistakes were 2.5 % fewer for

[1]No attempt has been made to offer interpretations for these higher-order interactions. They do not hold any obvious theoretical relevance for the hypotheses under investigation, and as such are not amenable to constructively meaningful interpretation. Nevertheless, the means are presented in Appendix 2.

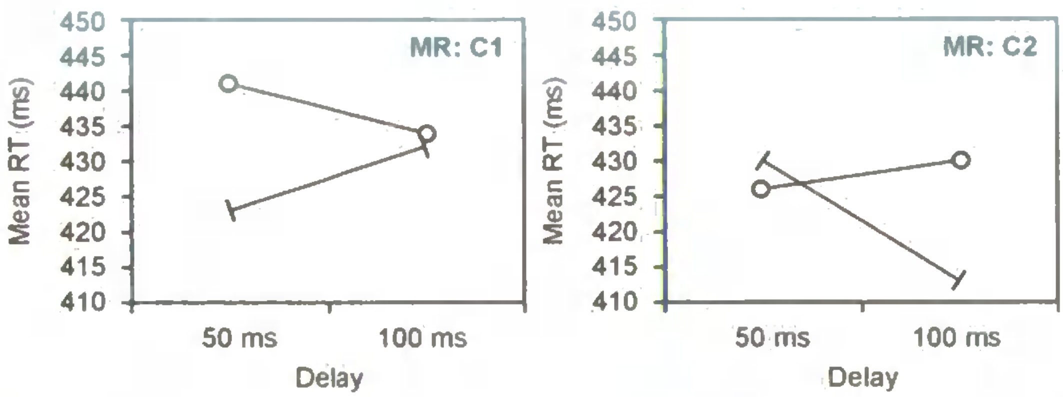
participants in MR: C2 (left response for yellow, right for orange: 2.3 %, SE = 0.7) than for participants in MR: C1 (left response for orange, right for yellow: 4.8 %, SE = 0.7).

Main Effects [4.2.2]

There was a significant main effect of delay in mistakes [F (1, 18) = 5.589, $p < 0.05$] but not in RTs [F (1, 18) = 1.721, $p > 0.1$]. Mean mistakes were 1.2 % fewer at delays of 50 ms (3.0 %, SE = 0.4) than at delays of 100 ms (4.2 %, SE = 0.7).

Three-Way Interactions [4.2.5]

There was a significant interaction between delay, hand of response and mapping rule in RTs, [F (1, 18) = 13.820, $p < 0.005$] but not in mistakes [F (1, 18) = 0.124, $p < 0.5$] (see Figure 8.9).



KEY

- Left response
- Right response

MEANS TABLE

MR	Del (ms)	Res	ms	SE
C1	50	L	441	14
C1	50	R	423	15
C1	100	L	434	15
C1	100	R	432	14
C2	50	L	426	14
C2	50	R	430	15
C2	100	L	430	15
C2	100	R	413	14

Figure 8.9 Mean RTs as a function of delay, hand of response and mapping rule.

As an overall pattern, mean RTs were fastest for participants in MR: C2 for both hands in both delays, with the exception of right hand responses at delays of 50 ms, where mean RTs were fastest for participants in MR: C1. More specifically, at delays of 50 ms the following pattern was observed: For left hand responses, mean RTs were 15 ms faster for participants in MR: C2 rather than MR: C1. For right hand responses, mean RTs were 7 ms faster for participants in MR: C1 rather than MR: C2. At delays of 100 ms the following pattern was observed: For left hand responses, mean RTs were 4 ms faster for participants in MR: C2 rather than MR: C1. For right hand responses, mean RTs were 19 ms faster for participants in MR: C2 rather than MR: C1.

8.2.4 Experiment 4.3

Main Effects [4.3.1]

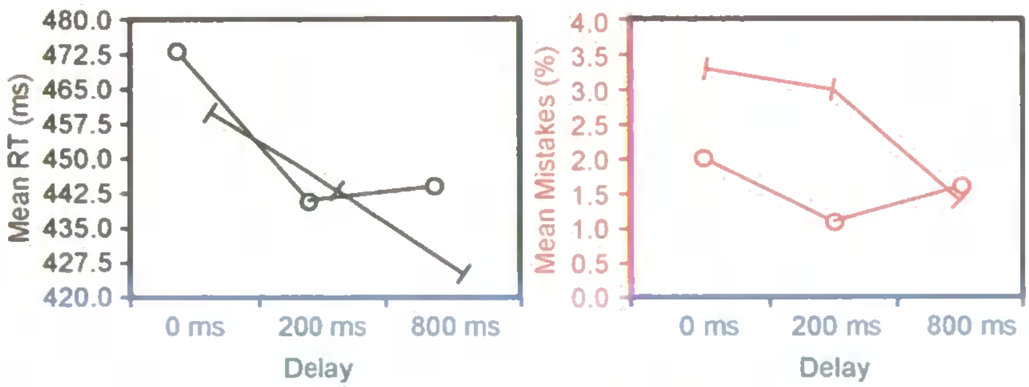
There was a significant main effect of delay in both RTs [F (2, 28) = 19.070, $p < 0.001$] and mistakes [F (2, 28) = 4.157, $p < 0.05$]. Mean RTs were as follows: 800 ms delays (435 ms, SE = 12); 200 ms delays (442 ms, SE = 11); 0 ms delays (467 ms, SE = 14). Mean mistakes were as follows: 800 ms delays (1.5 %, SE = 0.4); 200 ms delays (2.0 %, SE = 0.4); 0 ms delays (2.6 %, SE = 0.5). Thus mean RTs were 7 ms faster (and mean mistakes 0.5 % fewer) for delays of 800 ms rather than 200ms, and mean RTs were 25 ms faster (and mean mistakes 0.6 % fewer) for delays of 200 ms rather than 0ms.

Main Effects [4.3.2]

There was a main effect of hand of response, which approached significance in RTs [F (1, 14) = 3.847, $p = 0.07$] and was significant in mistakes [F (1, 14) = 4.717, $p < 0.05$]. Mean RTs were 10 ms faster for right (443 ms, SE = 12) rather than left (453 ms, SE = 13) hand responses. Mean mistakes were 0.9 % fewer for left (1.6 %, SE = 0.3) rather than right (2.5 %, SE = 0.6) hand responses. This suggested a speed/accuracy trade-off whereby right hand responses were faster at the cost of more mistakes.

Two-Way Interactions [4.3.4]

There was a significant interaction between delay and hand of response in both RTs [F (2, 28) = 8.896, $p < 0.005$] and mistakes [F (2, 28) = 3.341, $p = 0.05$] (see Figure 8.10). At delays of 0 ms, mean RTs were 13 ms faster for right rather than left hand responses. Similarly, at delays of 800 ms, mean RTs were 19 ms faster for right rather than left hand responses. However, at delays of 200 ms, mean RTs were similar for left and right hand responses (left hand responses were just 2 ms faster than right). A different pattern was revealed in the mistakes. At delays of 0 ms, mean mistakes were 1.3 % fewer for left rather than right hand responses. Similarly, at delays of 200 ms, mean mistakes were 1.9 % fewer for left rather than right hand responses. However, at delays of 800 ms, mean mistakes were similar for left and right hand responses (right hand responses made just 0.2 % fewer mean mistakes than left).



KEY

Left response

Right response

MEANS TABLE

Del (ms)	Res	ms	SE	%	SE
0	L	473	15	2.0	0.3
0	R	460	14	3.3	0.8
200	L	441	12	1.1	0.4
200	R	443	11	3.0	0.8
800	L	444	13	1.6	0.5
800	R	425	12	1.4	0.4

Figure 8.10 Mean RTs (black) and mean mistakes (red) as a function of hand of response and delay.

8.2.5 Experiment 5.1

Main Effects [5.1.2]

There was a significant main effect of hand of response in mistakes, [F (1, 18) = 8.380, p = 0.01] but not in RTs [F (1, 18) = 1.546, p > 0.1]. Mean mistakes were 2.2 % fewer for left hand responses (6.5 %, SE: 0.4), rather than right (8.7 %, SE: 0.5).

Two-Way Interactions [5.1.5]

There was a significant interaction between mapping rule and hand of response in RTs [F(1, 18) = 8.717, p = 0.009)] but not in mistakes [F(1, 18) = 2.185, p > 0.1)] (see Figure 8.11). For participants in MR: C1 (wobbly pattern/left response, straight pattern/right response), mean RTs were 13 ms faster for right hand responses (straight pattern) rather than left (wobbly pattern). For participants in <u>MR: C2</u> (wobbly pattern/right response, straight pattern/left response), mean RTs were 5 ms faster for left hand responses (straight pattern) rather than right (wobbly pattern). This suggested that participants responded fastest to cylinders with a straight pattern (perhaps because they found this pattern the easiest to identify).

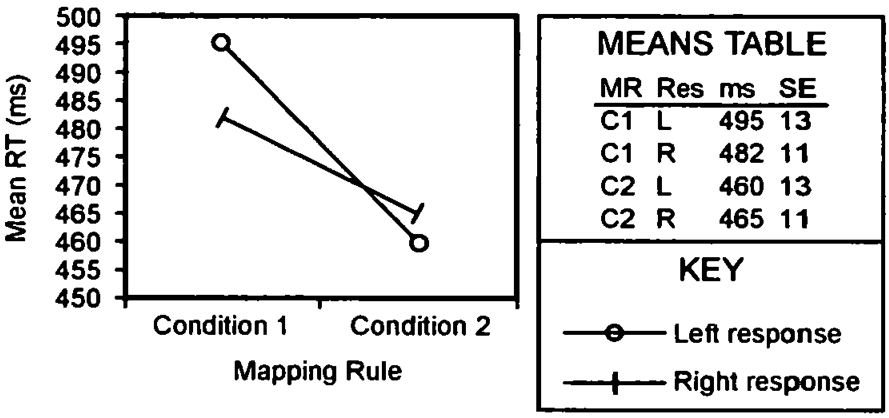
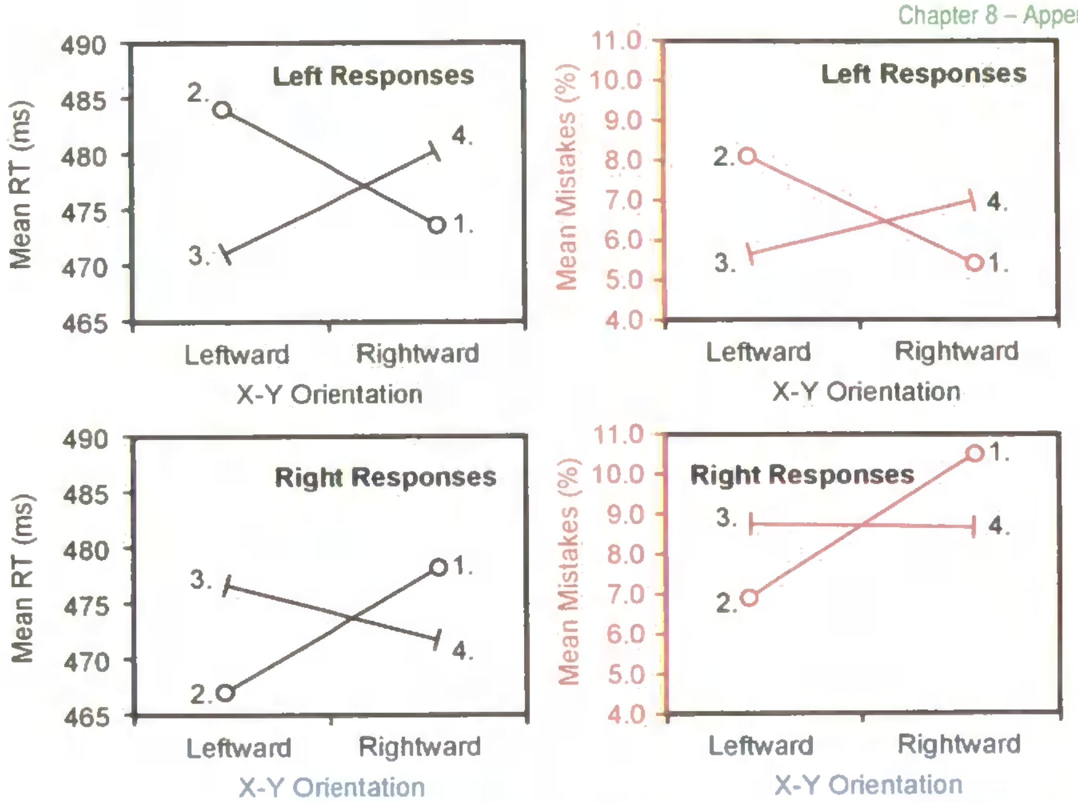


Figure 8.11 Mean RTs as a function of hand of response and mapping rule

Three-Way Interactions [5.1.6b]

Figure 8.12 reports the pattern of means for the statistically equivalent result to the interaction reported in the main text [5.1.6a✓]; namely an interaction between X-Y, Y-Z cylinder orientation and hand of response in both RTs [F (1, 18) = 17.535, p = 0.001] and mistakes [F (1, 18) = 6.511, p < 0.05]. From this perspective it can be seen how each specific global cylinder orientation was responded to. The main feature of interest however, is better described by result [5.1.6a✓], where it is apparent that cylinders oriented leftwards in the X-Z plane were responded to faster and more accurately with the left rather than right hand, and cylinders oriented rightwards in the X-Z plane were responded to faster and more accurately with the right rather than left hand.



KEY
- Upward (Y-Z)
- Downward (Y-Z)

MEANS TABLE

X-Y	Y-Z	Res	ms	SE	%	SE
L	D	L	471	10	5.6	0.8
L	D	R	477	9	8.7	0.7
L	U	L	484	9	8.1	1.0
L	U	R	467	9	6.9	1.1
R	D	L	480	9	7.0	0.6
R	D	R	472	7	8.6	1.0
R	U	L	474	9	5.5	0.9
R	U	R	478	8	10.5	1.2

GLOBAL ORIENT

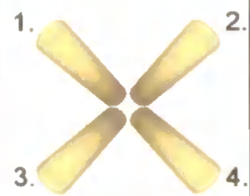


Figure 8.12 Mean RTs (black) and mean mistakes (red) as a function of X-Y, Y-Z cylinder orientation and hand of response.

8.2.6 Experiment 5.2

Main Effects [5.2.2]

There was a significant main effect of X-Y cylinder orientation in mistakes, [F (1, 18) = 13.042, $p < 0.01$] but not in RTs [F (1, 18) = 0.042, $p > 0.5$]. Mistakes were 1.2 % fewer for cylinders oriented rightwards (5.0 %, SE = 0.4) rather than leftwards (6.2 %, SE = 0.5) in the X-Y plane. Interestingly, no main effects were found for X-Y cylinder orientation in the previous experiment, or in Chapter 4 (which used 2D lines). Furthermore, there was a main effect of X-Z object orientation in Experiment 3.1, which although in RTs, reflected the same advantage for right orientations. Although the real objects of Experiment 3.1

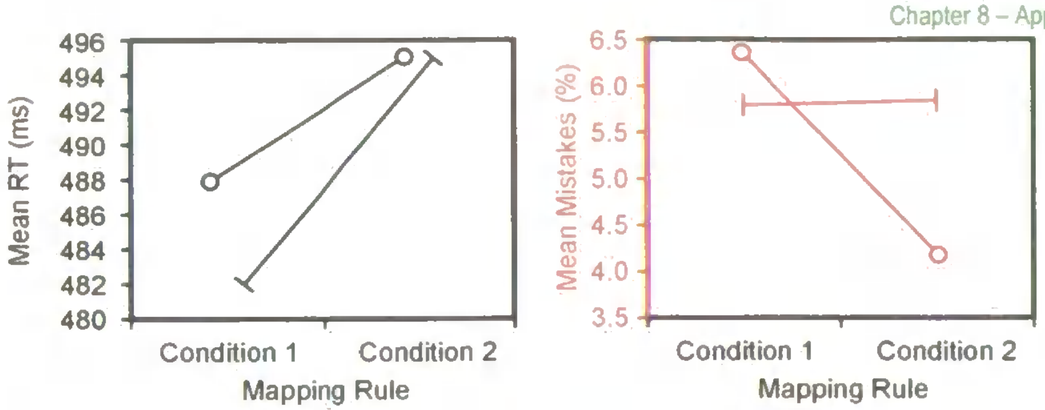
were essentially oriented in the X-Z plane, on the screen their orientations nevertheless also portrayed an element of X-Y orientation.

Main Effects [5.2.3]

There was a significant main effect of hand of response in mistakes, [F (1, 18) = 5.646, $p < 0.05$] but not in RTs [F (1, 18) = 0.369, $p > 0.5$]. Mistakes were 1.3 % fewer for left (4.9 %, SE = 0.3) rather than right (6.2 %, SE = 0.6) hand responses.

Two-Way Interactions [5.2.6]

There was an interaction between X-Z cylinder orientation and mapping rule, which approached significance in RTs [F (1, 18) = 4.325, $p = 0.052$] and was significant in mistakes [F (1, 18) = 5.676, $p < 0.05$] (see Figure 8.13). For participants in MR: C1 (wobbly pattern/left response, straight pattern/right response), mean RTs were 6 ms faster for cylinders oriented rightwards rather than a leftwards in the X-Z plane. For participants in MR: C2 (wobbly pattern/right response, straight pattern/left response), mean RTs were the same for cylinders oriented leftwards and rightwards in the X-Z plane (M = 495 ms). A different pattern was observed for mistakes. For cylinders oriented leftwards in the X-Z plane, mean mistakes were 2.2 % fewer at MR: C2, rather than MR: C1. However, for cylinders oriented rightwards in the X-Z plane, mean mistakes were similar across mapping conditions (mean mistakes were 0.1 % fewer for participants in MR: C1, rather than MR: C2).



KEY

- Leftward (X-Z)
- Rightward (X-Z)

MEANS TABLE

MR	X-Z	ms	SE	%	SE
C1	L	488	13	6.4	0.7
C1	R	482	13	5.8	0.6
C2	L	495	13	4.2	0.7
C2	R	495	13	5.9	0.6

X-Z ORIENT

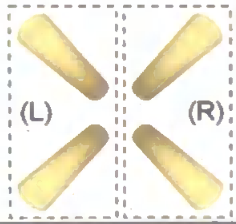
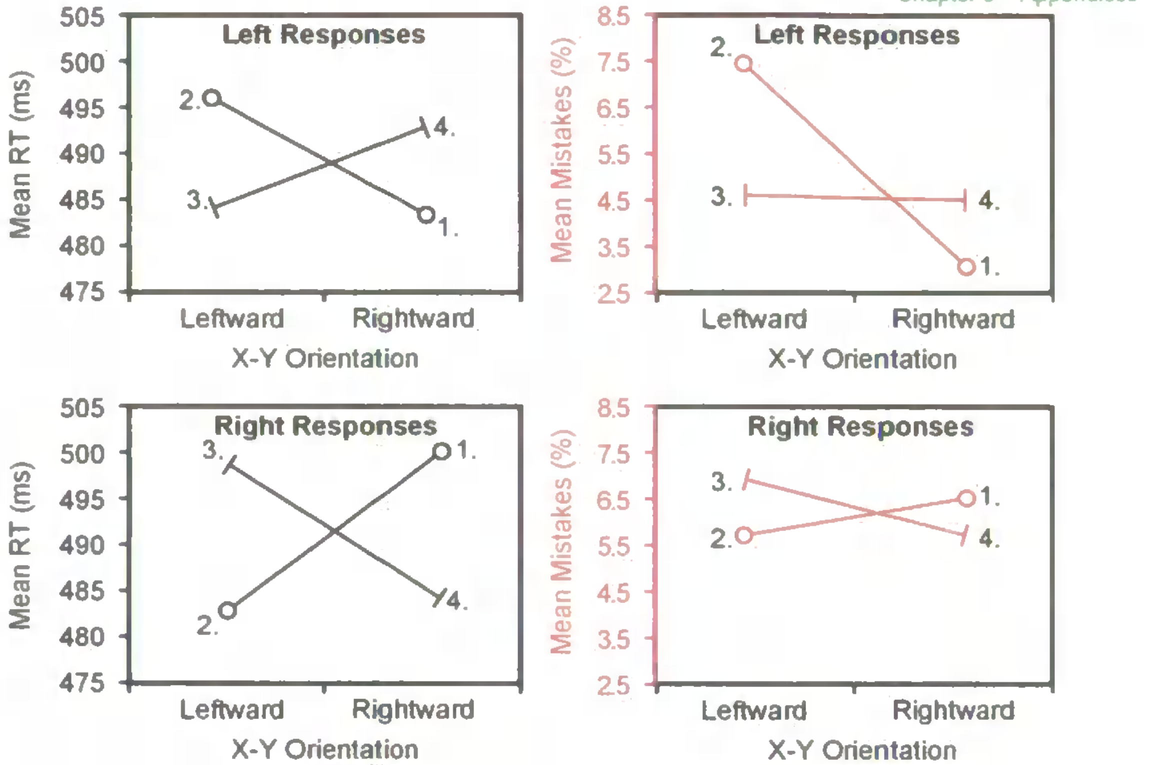


Figure 8.13 Mean RTs (black) and mean mistakes (red) as a function of mapping rule and X-Z orientation

Three-Way Interactions [5.2.7b]

Figure 8.14 reports the pattern of means for the statistically equivalent result to the interaction reported in the main text [5.2.7a✓]; namely an interaction between X-Y, Y-Z cylinder orientation and hand of response in both RTs [F (1, 18) = 45.509, $p < 0.001$] and mistakes [F (1, 18) = 8.995, $p < 0.01$]. From this perspective it can be seen how each specific global cylinder orientation was responded to. The main feature of interest however, is better described by result [5.2.7a✓], where it is apparent that cylinders oriented leftwards in the X-Z plane are responded to faster and more accurately with the left rather than right hand, and cylinders oriented rightwards in the X-Z plane are responded to faster and more accurately with the right rather than left hand.



KEY

—o— Upward (Y-Z)

—+— Downward (Y-Z)

MEANS TABLE

X-Y	Y-Z	Res	ms	SE	%	SE
L	D	L	484	9	4.6	0.7
L	D	R	499	10	6.9	0.8
L	U	L	496	10	7.4	1.0
L	U	R	483	9	5.7	0.6
R	D	L	493	11	4.5	0.4
R	D	R	484	9	5.7	0.9
R	U	L	483	10	3.1	0.5
R	U	R	500	9	6.5	0.9

GLOBAL ORIENT

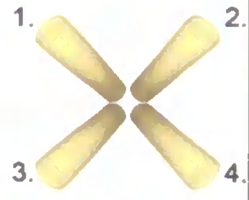


Figure 8.14 Mean RTs (black) and mean mistakes (red) as a function of X-Y, Y-Z cylinder orientation and hand of response

8.2.7 Experiment 5.3

Main Effects [5.3.1]

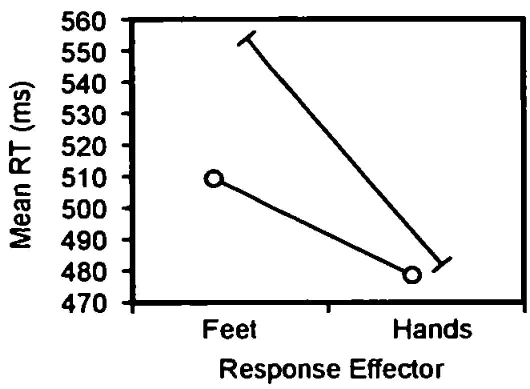
There was a significant main effect of effector in RTs [F (1, 16) = 63.274, $p < 0.001$] but not in mistakes [F (1, 16) = 0.251, $p > 0.5$]. Mean RTs were 50 ms faster for hand (481 ms, SE = 9) rather than foot (531 ms, SE = 12) responses.

Main Effects [5.3.2]

There was a significant main effect of spatial response in both RTs [F (1, 16) = 5.296, $p <$ 0.05] and mistakes [F (1, 16) = 10.117, $p > 0.01$]. Mean RTs were 8 ms faster (and mistakes were 1.7 % fewer) for left (502 ms, SE = 10; 5.1 %, SE = 0.5) rather than right (510 ms, SE = 11; 6.8 %, SE = 0.8) spatial responses.

Two-Way Interactions [5.3.7]

There was a significant interaction between effector and mapping rule 2 in RTs [F (1, 16) = 10.606, p = 0.005] but not in mistakes [F (1, 16) = 1.855, p > 0.1] (see Figure 8.15). For foot responses, mean RTs were 45 ms faster for participants in MR2: C1 (hands first, then feet) than for participants in MR2: C2 (feet first, then hands). For hand responses, mean RTs were 3 ms faster for participants in MR2: C1 than for participants in MR2: C2. This suggested that when just hand responses are considered, the two conditions of mapping rule 2 did not have a differential influence; whereas when just foot responses are considered, mean RTs were considerably slower when they were the responses that began the experiment.



MEANS TABLE

MR2	Eff	ms	SE
C1	H	479	13
C1	F	509	17
C2	H	482	13
C2	F	554	17

KEY

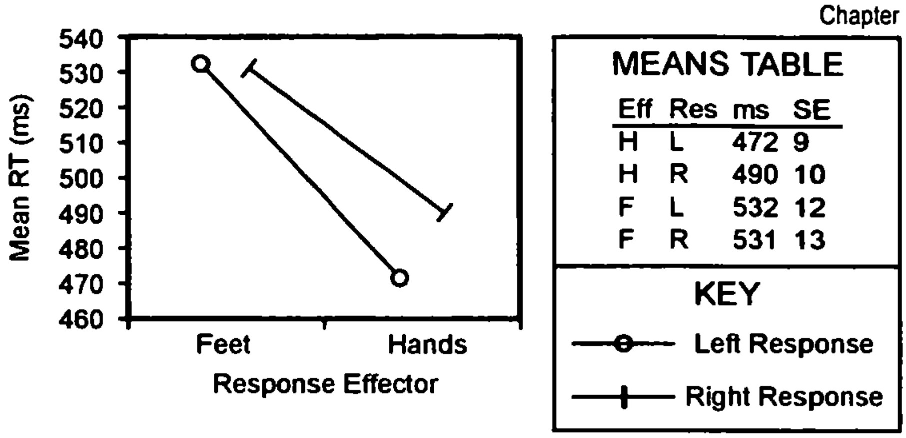
—o— MR2-C1

—+— MR2-C2

Figure 8.15 Mean RTs as a function of mapping rule 2 and response effector

Two-Way Interactions [5.3.8]

There was a significant interaction between effector and spatial response in RTs [F (1, 16) = 12.324, p < 0.005] but not in mistakes [F (1, 16) = 2.558, p > 0.1] (see Figure 8.16).



MEANS TABLE

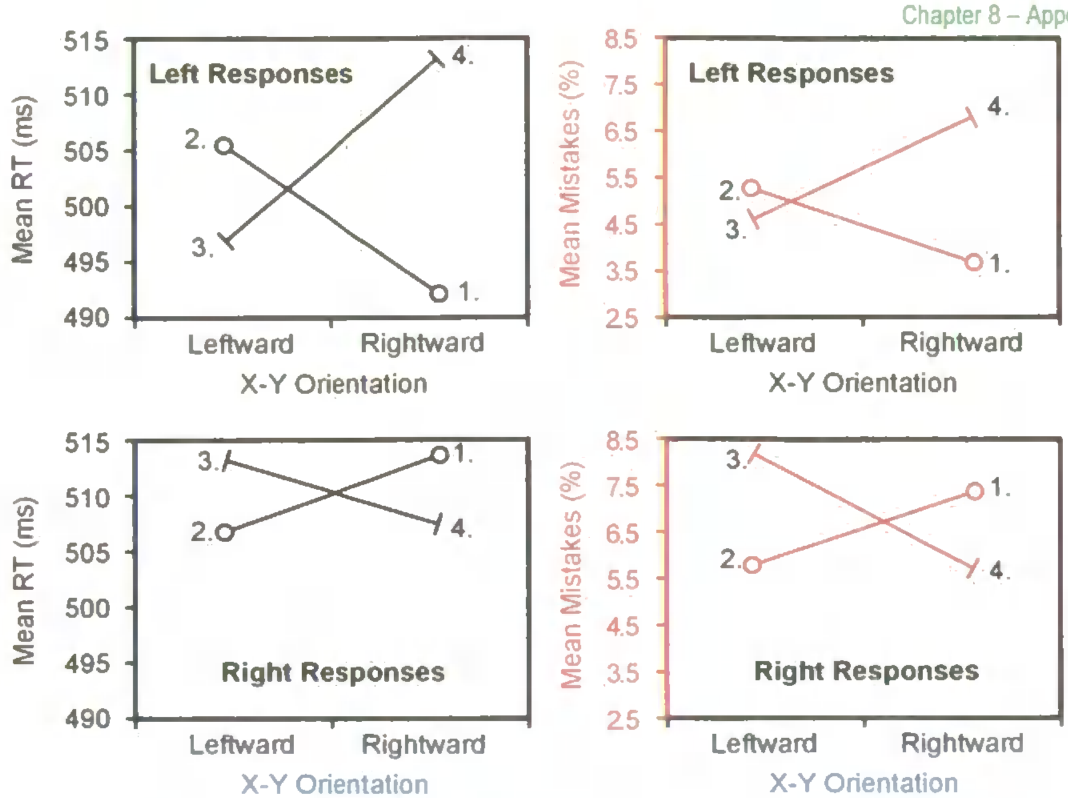
Eff	Res	ms	SE
H	L	472	9
H	R	490	10
F	L	532	12
F	R	531	13

Figure 8.16 Mean RTs as a function of spatial response and response effector

For foot responses, mean RTs were only 1 ms faster for left rather than right responses. For hand responses, mean RTs were 18 ms faster for left rather than right responses. This suggested that hand responses were primarily responsible for the main effect [5.3.2] of spatial response (reflecting an advantage for left spatial responses).

Three-Way Interactions [5.3.9b]

Figure 8.17 reports the pattern of means for the statistically equivalent result to the interaction reported in the main text [5.3.9a✓]; namely an interaction between X-Y, Y-Z cylinder orientation and spatial response in both RTs [F (1, 16) = 36.011, $p < 0.001$] and mistakes [F (1, 16) = 14.632, $p = 0.001$].



KEY

- —o— Upward (Y-Z)
- —+— Downward (Y-Z)

MEANS TABLE

X-Y	Y-Z	Res	ms	SE	%	SE
L	D	L	497	11	4.6	0.8
L	D	R	513	11	8.2	1.5
L	U	L	505	9	5.3	0.7
L	U	R	507	11	5.8	0.8
R	D	L	513	10	6.8	0.7
R	D	R	507	11	5.7	0.6
R	U	L	492	10	3.7	0.6
R	U	R	514	11	7.3	1.0

GLOBAL ORIENT

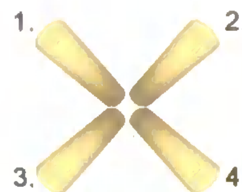
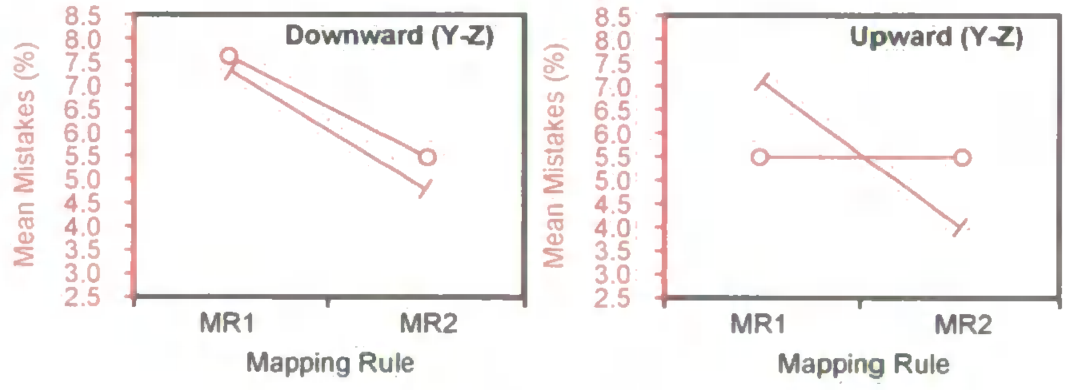


Figure 8.17 Mean RTs (black) and mean mistakes (red) as a function of X-Y, Y-Z cylinder orientation and hand of response

From this perspective it can be seen how each specific global cylinder orientation was responded to. Furthermore, the overall advantage for left over right spatial responses (as seen earlier [5.3.2 & 5.3.7]) can be seen clearly in the discrepancy between the upper graphs (left spatial responses) and the lower graphs (right spatial responses). The main feature of interest however, is better described by result [5.3.9a✓], where it is apparent that cylinders oriented leftwards in the X-Z plane are responded to faster and more accurately with left rather than right spatial responses, and cylinders oriented rightwards in the X-Z plane are responded to faster and more accurately with right rather than left spatial responses.

Three-Way Interactions [5.3.10]

There was a significant interaction between mapping rule 1, mapping rule 2 and Y-Z cylinder orientation in mistakes [F (1, 16) = 4.799, $p < 0.05$] but not in RTs [F (1, 16) = 0.065, $p > 0.5$]. For cylinders oriented downwards in the Y-Z plane (see almost parallel solid lines in the left graph of Figure 8.18) mapping rules did not appear to interact; overall however, mean mistakes were considerably fewer under MR2 (surface pattern mapping) rather than MR1 (effector mapping). Examining this pattern under different mapping conditions, mean mistakes were 0.3 % fewer for participants in MR1: C2 (wobbly pattern/right response, straight pattern/left response) rather than MR1: C1 (wobbly pattern/left response, straight pattern/right response) and mean mistakes were 0.7 % fewer for participants in MR2: C2 (feet first/ hands second) rather than MR2: C1 (hands first/ feet second). For cylinders oriented upwards in the Y-Z plane (see disordinal interaction of the right graphs in Figure 8.18) the following pattern was observed: mean mistakes were 1.6 % fewer for participants in MR1: C1 rather than MR1: C2, and mean mistakes were 1.6 % fewer for participants in MR2: C2 rather than MR2: C1.



KEY

- MR: C1
- MR: C2

MEANS TABLE

MR1	MR2	Y-Z	%	SE
C1	C1	D	7.6	1.4
C1	C1	U	5.5	1.1
C1	C2	D	7.3	1.4
C1	C2	U	7.1	1.1
C2	C1	D	5.5	1.4
C2	C1	U	5.5	1.1
C2	C2	D	4.8	1.4
C2	C2	U	3.9	1.1

Y-Z ORIENT

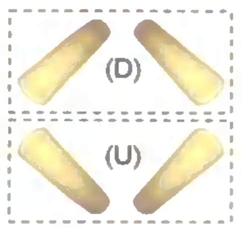
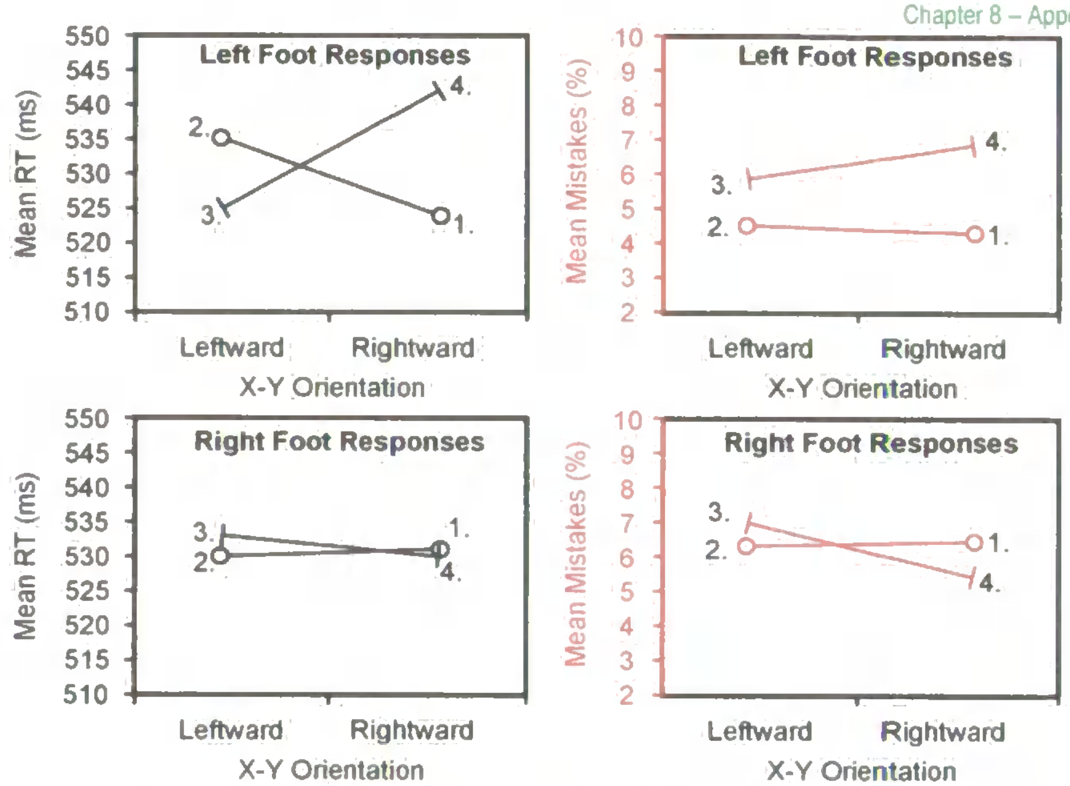


Figure 8.18 Mean mistakes as a function of mapping rules 1 & 2 and Y-Z orientation

Higher-order Interactions [5.3.11b]

Figures 8.19 and 8.20 report the pattern of means for the statistically equivalent result to the interaction reported above [5.3.11a↯]; namely an interaction between effector, X-Y, Y-Z cylinder orientation and spatial response in mistakes [$F\,(1, 16) = 8.771, p < 0.01$] (and the equivalent in RTs that was not statistically significant [$F\,(1, 16) = 1.438, p > 0.1$]).

From this perspective it can be seen how each specific global cylinder orientation was responded to (see). The main feature of interest however, is better described by result [5.3.11a↯]; where it is apparent that the size of the compatibility effect between spatial responses and compatible X-Z cylinder orientations is more pronounced for hand power grip responses than for foot responses (although this was not statistically significant in RTs).



KEY

Upward (Y-Z)

Downward (Y-Z)

MEANS TABLE

Eff	X-Y	Y-Z	Res	ms	SE	%	SE
F	L	D	L	525	13	5.8	1.2
F	L	D	R	533	14	7.0	1.7
F	L	U	L	535	11	4.5	0.8
F	L	U	R	530	13	6.3	1.1
F	R	D	L	542	11	6.8	1.0
F	R	D	R	530	13	5.4	0.7
F	R	U	L	524	13	4.3	0.9
F	R	U	R	531	14	6.4	1.3

GLOBAL ORIENT

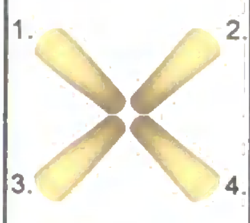
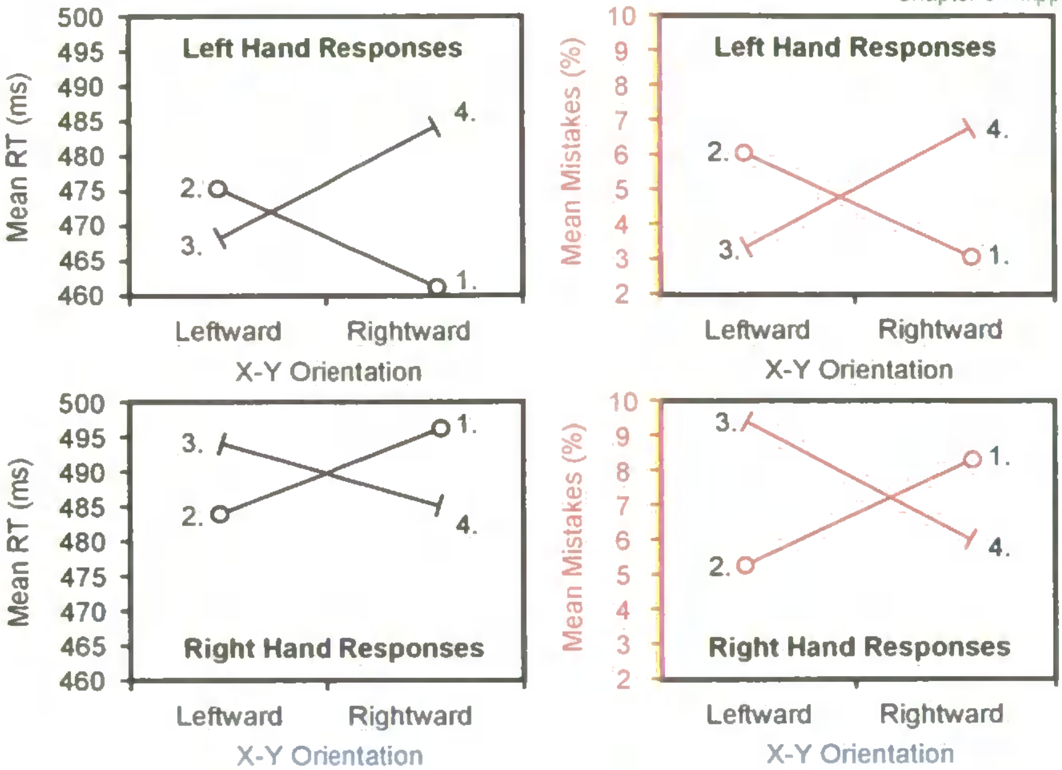


Figure 8.19 Mean RTs (black, blue) and mean mistakes (reds) as a function of effector (n.b. foot responses in this figure), X-Y, Y-Z orientation and spatial response



KEY

- Upward (Y-Z)
- Downward (Y-Z)

MEANS TABLE

Eff	X-Y	Y-Z	Res	ms	SE	%	SE
H	L	D	L	468	11	3.4	0.7
H	L	D	R	494	10	9.4	1.6
H	L	U	L	475	8	6.0	1.1
H	L	U	R	484	10	5.3	0.8
H	R	D	L	484	9	6.7	0.8
H	R	D	R	485	10	6.0	1.0
H	R	U	L	461	9	3.1	0.7
H	R	U	R	496	11	8.3	1.0

GLOBAL ORIENT

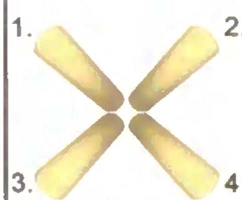


Figure 8.20 Mean RTs (black, blue) and mean mistakes (reds) as a function of effector (n.b. foot responses in this figure), X-Y, Y-Z orientation and spatial response

Higher-order Interactions [5.3.12 - 5.3.14]

There was a significant interaction between mapping rule 1, effector, X-Y cylinder orientation and spatial response in RTs [F (1, 16) = 9.596, $p < 0.01$] but not in mistakes [F (1, 16) = 2.975, $p > 0.1$].

There was a significant interaction between mapping rule 1, mapping rule 2, effector, X-Y cylinder orientation and spatial response in RTs [F (1, 16) = 4.562, $p < 0.05$] but not in mistakes [F (1, 16) = 0.569, $p > 0.1$].

There was a significant interaction between mapping rule 1, mapping rule 2, effector, X-Z cylinder orientation and spatial response in mistakes [F (1, 16) = 6.618, $p < 0.05$] but not in RTs [F (1, 16) = 0.444, $p > 0.5$].

Means and standard errors for these higher-order interactions [5.3.12-5.3.14] are located in Appendix 3.

8.2.8 Experiment 6.1

Main Effects [6.1.2]

There was a significant main effect for X-Y cylinder orientation in RTs [F (1, 18) = 4.747, $p < 0.05$] but not in mistakes [F (1, 18) = 0.001, $p > 0.5$]. Mean RTs were 3 ms faster for cylinders oriented leftwards (489 ms, SE = 12) rather than rightwards (492 ms, SE = 12) in the X-Y plane. The only other occasion that a main effect was found for X-Y cylinder orientation was in Experiment 5.2, which also used power grip responses. However, in Experiment 5.2 [5.2.2], mean mistakes were fewer for cylinders oriented rightwards rather than leftwards (note the different performance measure of mistakes).

Main Effects [6.1.3]

There was a significant main effect for delay in RTs, [F (2, 36) = 101.585, $p < 0.001$] but not in mistakes [F (2, 36) = 0.491, $p > 0.5$]. Mean RTs were as follows: 0 ms delays (523 ms, SE = 12); 400 ms delays (477 ms, SE = 12); 800 ms delays (472 ms, SE = 13). Thus mean RTs were 5 ms faster at delays of 800 ms rather than 400 ms, and were 46 ms faster at delays of 400 ms rather than 0 ms. This suggested that the longer the delay, the faster the response. Under long delays, it is likely that afforded actions are already planned and if selected upon target presentation, can be quickly executed. Related to this argument, it is presumably the case that at one extreme (the 0 ms delay), the participant simultaneously processes all available information (various object properties, including the surface pattern). This heavy processing load takes time to do (hence, to an extent, response times suffer). However, at the other extreme (the 800 ms delay), a good deal of processing that is superfluous to task requirements (coding various object properties) can be achieved during the delay. When the target stimulus (the surface pattern) arrives, it is the only remaining processing task, and can be achieved quickly (hence, to an extent, response times benefit).

Main Effects [6.1.4]

There was a significant main effect for hand of response in mistakes, [F (1, 18) = 5.415, p < 0.05] but not in RTs [F (1, 18) = 0.588, p > 0.1]. Mean mistakes were 1.1 % fewer for left (3.5 %, SE = 0.5) rather than right (4.6 %, SE = 0.7) hand responses.

Two-Way Interactions [6.1.5]

There was a significant interaction between mapping rule and hand of response in mistakes [F(1, 18) = 6.428, p < 0.05)] but not in RTs [F(1, 18) = 0.001, p > 0.5)] (see Figure 8.21).

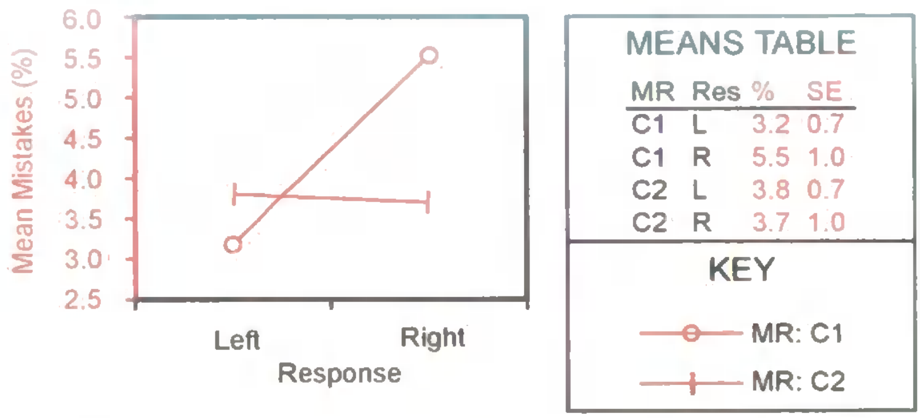
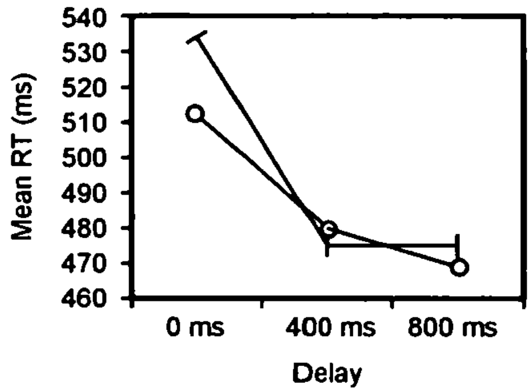


Figure 8.21 Mean mistakes as a function of hand of response and mapping rule

For <u>left hand responses</u>, mean mistakes were 0.6 % fewer for participants in MR: C1 (left responses were made to wobbly patterned cylinders) rather than MR: C2 (left responses were made to straight patterned cylinders). For <u>right hand responses</u>, mean mistakes were 1.8 % fewer for participants in MR: C2 (right responses were made to wobbly patterned cylinders) rather than MR: C1 (right responses were made to straight patterned cylinders). This suggested an advantage for responses made to wobbly patterned cylinders (perhaps because participants found this pattern the easiest to identify). Interestingly, when this interaction has proved significant before (for mean mistakes in Experiment 5.1 [5.1.5]), there was an opposite pattern whereby an advantage was shown for responses made to straight patterned cylinders.

Two-Way Interactions [6.1.6]

There was a significant interaction between mapping rule and delay in RTs [F (2, 36) = 6.201, p = 0.005] but not in mistakes [F (2, 36) = 0.287, p > 0.5] (see Figure 8.22). For participants in MR: C1, mean RTs were 11 ms faster at delays of 800 ms rather than 400ms, and mean RTs were 32 ms faster at delays of 400 ms rather than 0 ms. For participants in MR: C2, mean RTs were the same at delays of 800 ms and 400ms, and mean RTs were 59 ms faster at delays of 800 ms and 400 ms rather than 0 ms.



MEANS TABLE

MR	Del	ms	SE
C1	0	512	16
C1	400	480	17
C1	800	469	18
C2	0	534	16
C2	400	475	17
C2	800	475	18

KEY

—o— MR: C1

—+— MR: C2

Figure 8.22 Mean RTs as a function of delay and mapping rule

Two-Way Interactions [6.1.7]

There was a significant interaction between mapping rule and X-Z cylinder orientation in mistakes [F (1, 18) = 4.491, p < 0.05)] but not in RTs [F(1, 18) = 0.004, p > 0.5)] (see Figure 8.23). For cylinders oriented leftwards in the X-Z plane, mean mistakes were 1.2 % fewer for participants in MR: C2 rather than MR: C1. For cylinders oriented rightwards in the X-Z plane, mean mistakes were 0.2 % fewer for participants in MR: C1 rather than MR: C2.

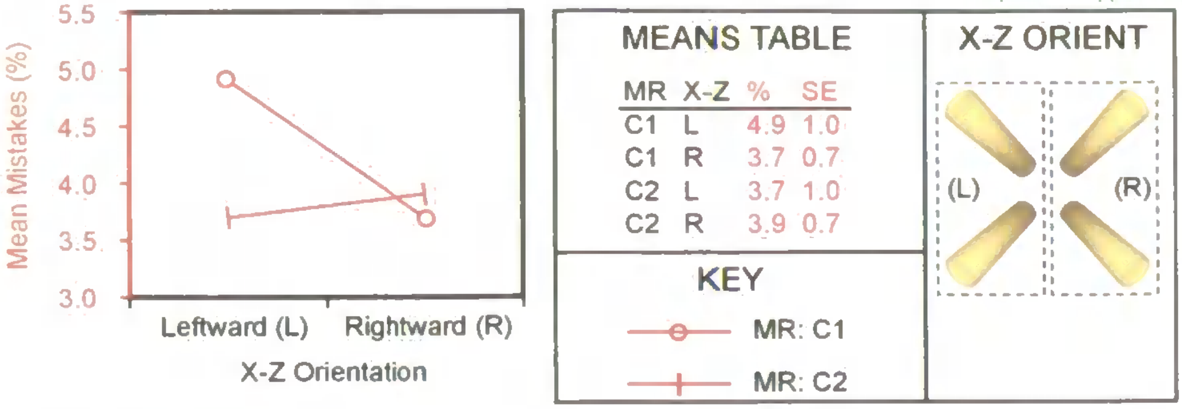
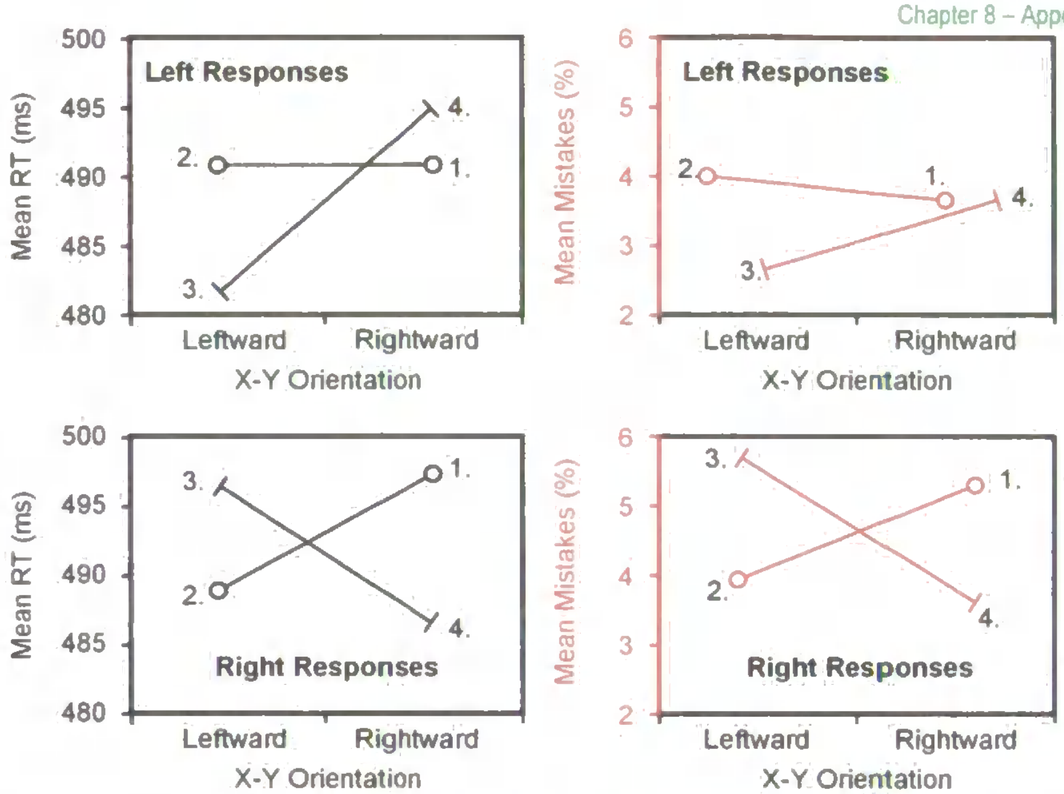


Figure 8.23 Mean mistakes as a function of mapping rule and X-Z cylinder orientation

Three-Way Interactions [6.1.10b✓]

Figure 8.24 reports the pattern of means for the statistically equivalent result to the interaction reported in the main text [6.1.10a✓]; namely an interaction between X-Y, Y-Z cylinder orientation and hand of response in both RTs [F (1, 18) = 52.785, $p < 0.001$] and mistakes [F (1, 18) = 5.115, $p < 0.05$]. From this perspective it can be seen how each specific global cylinder orientation was responded to. The main feature of interest however, is better described by result [6.1.10a✓], where it is apparent that cylinders oriented leftwards in the X-Z plane are responded to faster and more accurately with the left rather than right hand, and cylinders oriented rightwards in the X-Z plane are responded to faster and more accurately with the right rather than left hand.



KEY

- Upward (Y-Z)
- Downward (Y-Z)

MEANS TABLE

X-Y	Y-Z	Res	ms	SE	%	SE
L	D	L	482	12	2.7	0.5
L	D	R	496	12	5.7	1.2
L	U	L	491	13	4.0	0.7
L	U	R	489	12	3.9	0.7
R	D	L	495	12	3.7	0.8
R	D	R	487	12	3.6	0.6
R	U	L	491	13	3.7	0.7
R	U	R	497	12	5.3	0.9

GLOBAL ORIENT

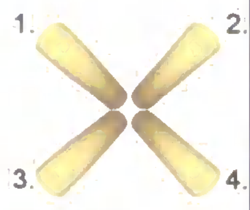
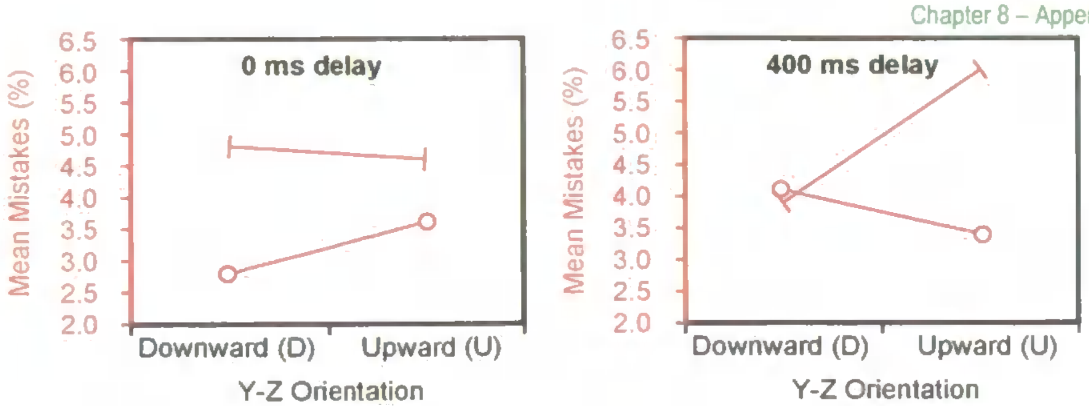
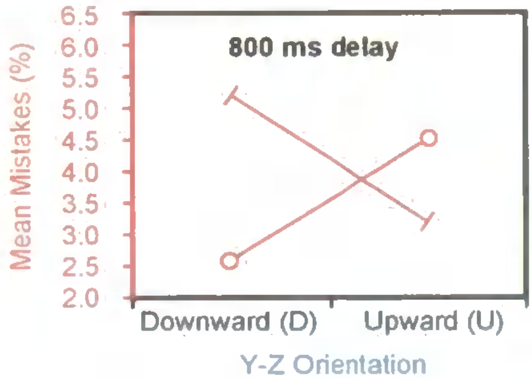


Figure 8.24 Mean RTs (black) and mean mistakes (red) as a function of X-Y, Y-Z cylinder orientation and hand of response

Three-Way Interactions [6.1.12]

There was a significant interaction between delay, Y-Z cylinder orientation and hand of response in mistakes [F (1, 18) = 5.331, $p < 0.01$] but not in RTs [F (1, 18) = 0.106, $p >$ 0.5] (see Figure 8.25).





MEANS TABLE

Del	Y-Z	Res	%	SE
0	D	L	2.8	0.6
0	D	R	4.8	1.1
0	U	L	3.6	0.6
0	U	R	4.6	0.8
400	D	L	4.1	1.1
400	D	R	3.9	0.8
400	U	L	3.4	0.6
400	U	R	6.0	1.1
800	D	L	2.6	0.6
800	D	R	5.2	1.2
800	U	L	4.5	0.8
800	U	R	3.2	0.6

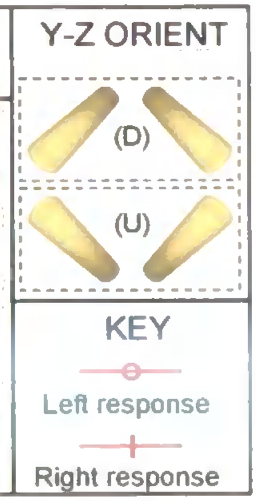


Figure 8.25 Mean mistakes as a function of delay, Y-Z cylinder orientation and hand of response

At delays of 0 ms, the following pattern was observed: For left hand responses, mean mistakes were 0.8 % fewer for cylinders oriented downwards rather than upwards in the Y-Z plane. For right hand responses, mean mistakes were 0.2 % fewer for cylinders oriented upwards rather than downwards in the Y-Z plane. At delays of 400 ms, the following pattern was observed: For left hand responses, mean mistakes were 0.7 % fewer for cylinders oriented upwards rather than downwards in the Y-Z plane. For right hand responses, mean mistakes were 2.1 % fewer for cylinders oriented downwards rather than upwards in the Y-Z plane. At delays of 800 ms, the following pattern was observed: For left hand responses, mean mistakes were 1.9 % fewer for cylinders oriented downwards rather than upwards in the Y-Z plane. For right hand responses, mean mistakes were 2 % fewer for cylinders oriented upwards rather than downwards in the Y-Z plane.

8.2.9 Experiment 6.2

Main Effects [6.2.2]

There was a significant main effect for hand of response in both RTs, [$F(1, 18) = 33.266$, $p < 0.001$] and mistakes [$F(1, 18) = 5.737$, $p < 0.05$]. Mean RTs were 27 ms faster (and mistakes were 1.9 % fewer) for left (581 ms, SE = 11; 4.1 %, SE = 0.7) rather than right (608 ms, SE = 12; 6.0 %, SE = 1.0) hand responses.

Main Effects [6.2.3]

There was a significant main effect for X-Y cylinder orientation in mistakes [$F(1, 18) = 19.794$, $p < 0.001$] but not in RTs [$F(1, 18) = 1.022$, $p > 0.1$]. Mean mistakes were 1.5 % fewer for cylinders oriented leftwards (4.3 %, SE = 0.8) rather than rightwards (5.8 %, SE = 0.8) in the X-Y plane. A similar advantage for cylinders oriented leftwards in the X-Y plane was previously found for man RTs in Experiment 6.1 (see result [6.1.2]).

Two-Way Interactions [6.2.7]

There was a significant interaction between mapping rule and X-Y cylinder orientation in mistakes [$F(1, 18) = 15.528$, $p = 0.001$] but not in RTs [$F(1, 18) = 0.000$, $p = 1.000$] (see Figure 8.26). For participants in MR: C1 (wobbly pattern/ left responses, straight pattern/ right), mean mistakes were 2.7 % fewer for cylinders oriented leftwards rather than rightwards in the X-Y plane. For participants in MR: C2 (wobbly pattern/ right responses, straight pattern/left), mean mistakes were 0.2 % fewer for cylinders oriented leftwards rather than rightwards in the X-Y plane. This suggested that the main effect of X-Y orientation reported earlier for mean mistakes [6.2.3] was largely down to those participants in MR: C1.

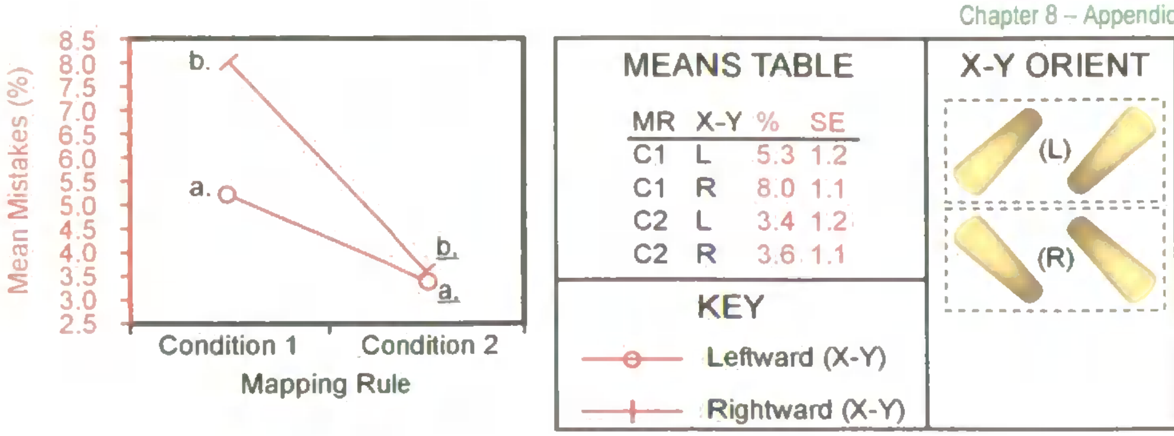


Figure 8.26 Mean mistakes as a function of X-Y cylinder orientation and mapping rule

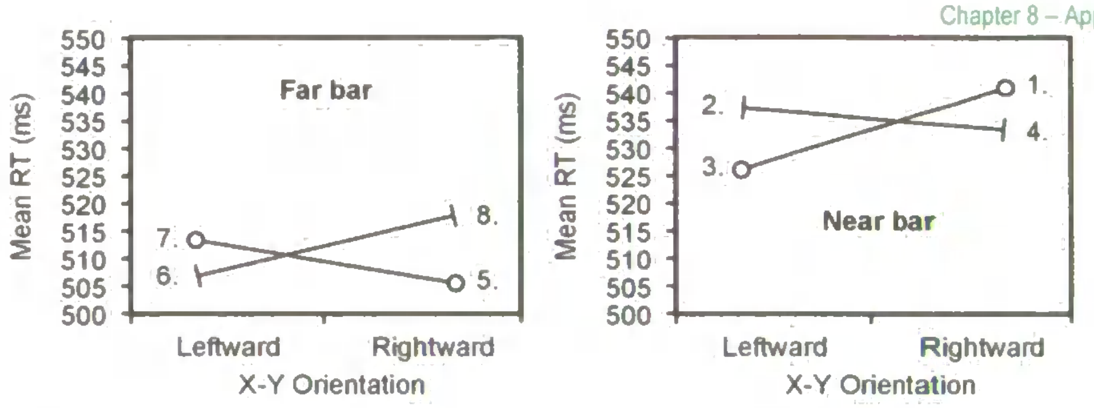
8.2.10 Experiment 6.3

Main Effects [6.3.2]

There was a significant main effect of hand of response in both RTs [F (1, 18) = 14.656, p = 0.001] and mistakes [F (1, 18) = 4.834, p < 0.05]. Mean RTs were 19 ms faster (and mean mistakes 1 % fewer) for right (513 ms, SE = 9.2; 4.4 %, SE = 0.5) rather than left (532 ms, SE = 10.2; 5.4 %, SE = 0.6) hand key press responses. This may reflect the predominance of right-handed participants, who would under most circumstances probably favour interacting with a lever with their right hand.

Three-Way Interactions [6.3.4b]

Figure 8.27 reports the pattern of means for the statistically equivalent result to the interaction reported in the main text [6.3.4a]; namely an interaction between X-Z bar position, X-Y and Y-Z cylinder orientation in RTs [F (1, 18) = 4.093, p = 0.058]. From this perspective it can be seen how fast each specific lever configuration was responded to. The main feature of interest however, is better described by result [6.3.4a], where it is apparent that regardless of the bar position there was an advantage for lever configurations that would require an upward rather than downward reach trajectory (which in this instance is reflected by an advantage for levers 3, 4, 5 and 6 over levers 1, 2, 7 and 8 respectively).



KEY

—o— Leftward (X-Z)
—+— Rightward (X-Z)

MEANS TABLE

(Lev)	Bar	X-Y	X-Z	ms	SE	%	SE
7	F	L	L	513	11	4.4	0.7
6	F	L	R	507	12	5.0	0.8
5	F	R	L	505	11	4.7	0.9
8	F	R	R	518	10	4.3	0.6
3	N	L	L	526	10	5.7	1.0
2	N	L	R	537	9	5.6	0.8
1	N	R	L	541	9	4.5	0.9
4	N	R	R	533	10	5.0	0.8

LEVERS (T1)

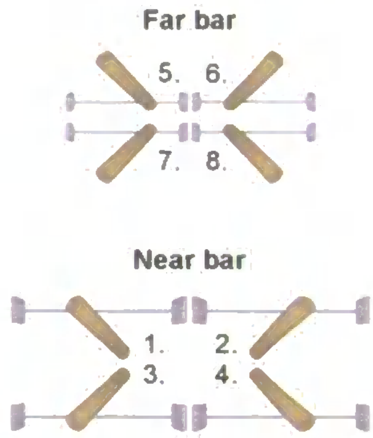
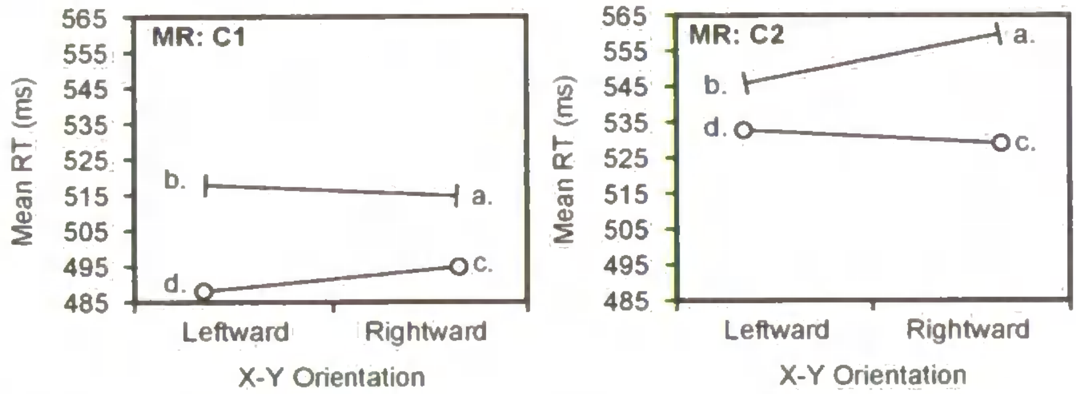


Figure 8.27 Mean RTs as a function of X-Y, X-Z cylinder orientation and hand of response.

Three-Way Interactions [6.3.5a]

There was a significant interaction between X-Z bar position, X-Y cylinder orientation and mapping rule in RTs [F (1, 18) = 9.882, $p < 0.01$] (see Figure 8.28) but not in mistakes [F (1, 18) = 0.764, $p > 0.1$]. The main effect of mapping rule [6.3.3] is apparent in this interaction (participants in MR: C1 responded faster than participants in MR: C2), as is the main effect of bar position [6.3.1] (where levers with a far bar were responded to faster than levers with a near bar. In addition, for participants in MR: C1 (left response/ lever up, right response/lever down) the following pattern was observed: when the bar position was far, mean RTs were 7 ms faster for cylinders oriented leftwards rather than rightwards in the X-Y plane. When the bar position was near, mean RTs were 3 ms faster for cylinders oriented rightwards rather than leftwards in the X-Y plane. For participants in MR: C2 (left response/ lever down, right response/lever up) the opposite pattern was observed: when the bar position was far, mean RTs were 4 ms faster for cylinders oriented rightwards rather than leftwards in the X-Y plane. When the bar position was near, mean RTs were 14 ms faster for cylinders oriented leftwards rather than rightwards in the X-Y plane.



KEY

Far bar
Near bar

MEANS TABLE

(Lev)	MR	Bar	X-Y	ms	SE
d.	1	F	L	487	15
c.	1	F	R	494	14
b.	1	N	L	517	13
a.	1	N	R	514	13
d.	2	F	L	533	15
c.	2	F	R	529	14
b.	2	N	L	546	13
a.	2	N	R	560	13

LEVERS (T1)

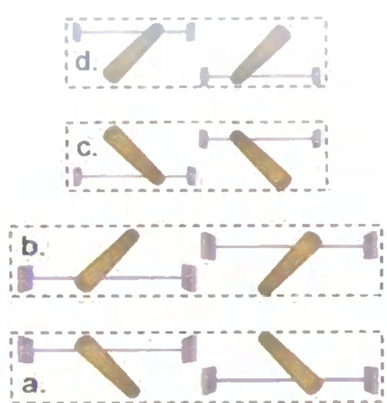
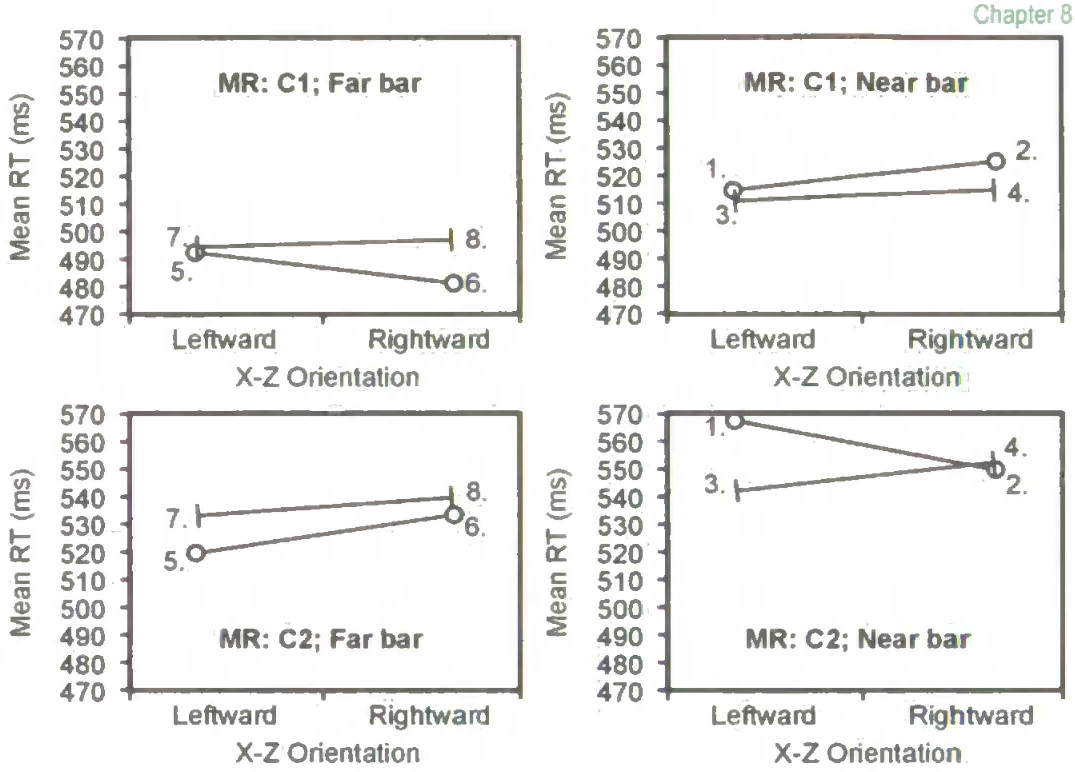
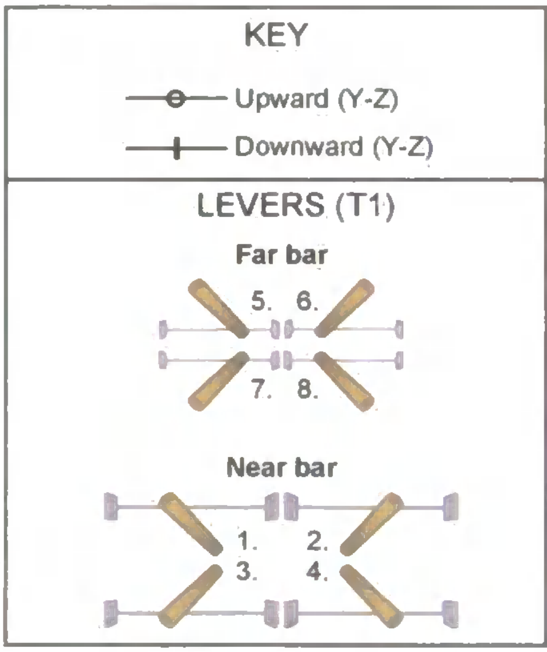


Figure 8.28 Mean RTs as a function of X-Z bar position, X-Y cylinder orientation and mapping rule

Higher-Order Interactions [6.3.5b]

Figure 8.29 reports the pattern of means for the statistically equivalent result to the interaction reported in the main text [6.3.5a]; namely an interaction between X-Z bar position, Y-Z, X-Z cylinder orientation and mapping rule in RTs [F (1, 18) = 9.882, p < 0.01]. From this perspective it can be seen how fast each specific lever configuration was responded to.





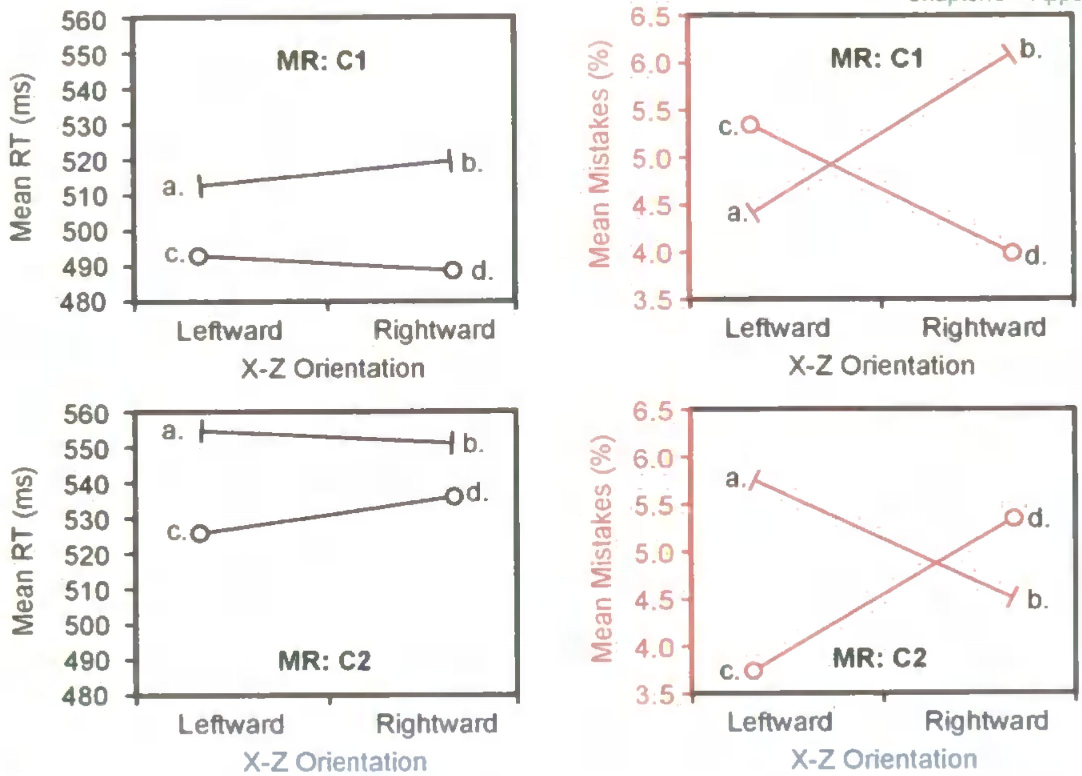
MEANS TABLE

(Lev)	MR	Bar	Y-Z	X-Z	ms	SE
7	1	F	D	L	494	15
8	1	F	D	R	496	15
5	1	F	U	L	492	16
6	1	F	U	R	481	16
3	1	N	D	L	510	14
4	1	N	D	R	514	14
1	1	N	U	L	514	13
2	1	N	U	R	525	12
7	2	F	D	L	533	15
8	2	F	D	R	539	15
5	2	F	U	L	519	16
6	2	F	U	R	533	16
3	2	N	D	L	542	14
4	2	N	D	R	552	14
1	2	N	U	L	567	13
2	2	N	U	R	550	12

Figure 8.29 Mean RTs as a function of X-Z bar position, Y-Z, X-Z cylinder orientation and mapping rule

Three-Way Interactions [6.3.6a]

There was a significant interaction between X-Z bar position, X-Z cylinder orientation and mapping rule in RTs [F (1, 18) = 5.994, $p < 0.05$] and in mistakes [F (1, 18) = 6.347, $p < 0.05$] (see Figure 8.30).



KEY

Far bar

Near bar

MEANS TABLE

(Lev)	MR	Bar	X-Z	ms	SE	%	SE
c	1	F	L	493	15	5.3	0.8
d	1	F	R	489	15	4.0	0.9
a	1	N	L	512	13	4.4	1.1
b	1	N	R	520	12	6.1	0.8
c	2	F	L	526	15	3.8	0.8
d	2	F	R	536	15	5.3	0.9
a	2	N	L	555	13	5.8	1.1
b	2	N	R	551	12	4.5	0.8

LEVERS (T1)

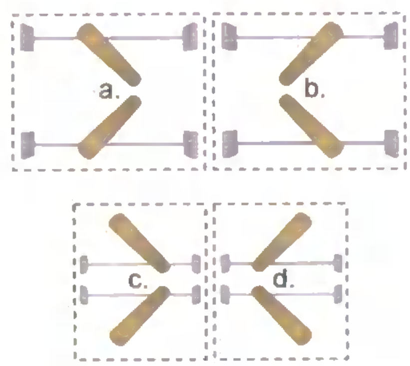


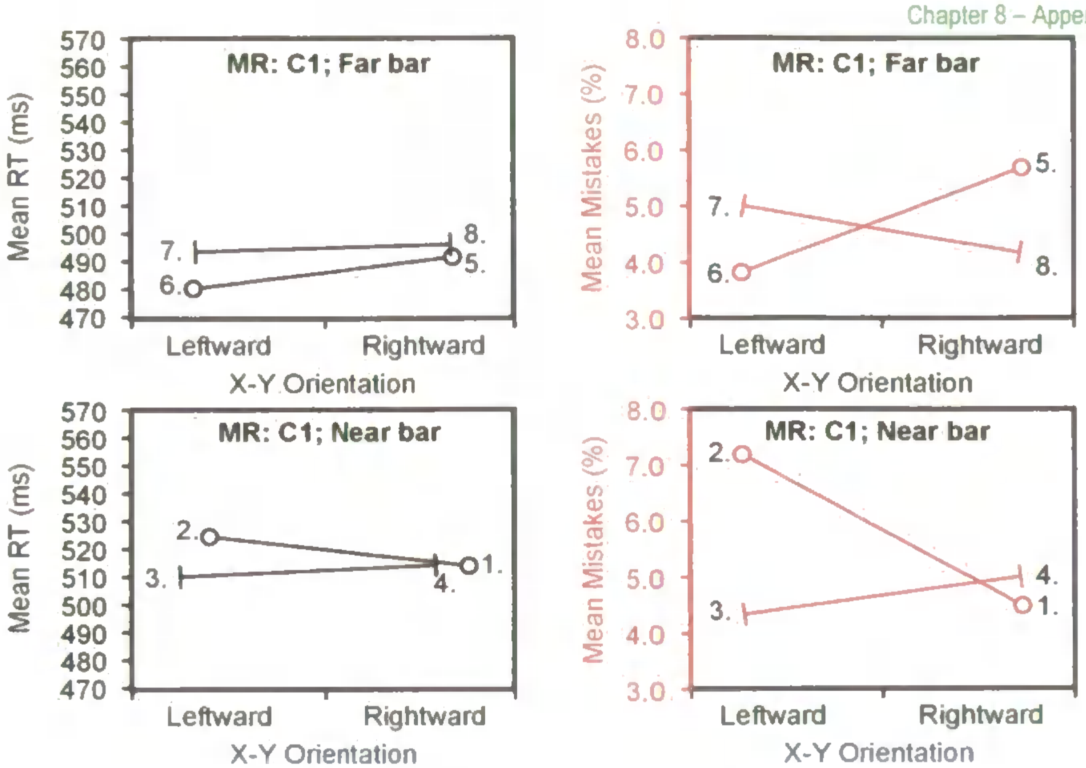
Figure 8.30 Mean RTs (black) and mean mistakes (red) as a function of X-Z bar position, X-Z cylinder orientation and mapping rule

The main effects of mapping rule (participants in MR: C1 responded faster than participants in MR: C2) and X-Z bar position (levers with far bars were responded to faster than levers with near bars) are again apparent in this interaction.

In addition, for participants in MR: C1 (left response/ lever up, right response/lever down) the following pattern was observed: when the bar position was far, mean RTs were 4 ms faster (and mistakes 1.3 % fewer) for cylinders oriented rightwards rather than leftwards in the X-Z plane. When the bar position was near, mean RTs were 8 ms faster (and mistakes 1.7 % fewer) for cylinders oriented leftwards rather than rightwards in the X-Z plane. For participants in MR: C2 (left response/ lever down, right response/lever up) the opposite pattern was observed: when the bar position was far, mean RTs were 10 ms faster (and mistakes 1.6 % fewer) for cylinders oriented leftwards rather than rightwards in the X-Z plane. When the bar position was near, mean RTs were 4 ms faster (and mistakes 1.3 % fewer) for cylinders oriented rightwards rather than leftwards in the X-Z plane.

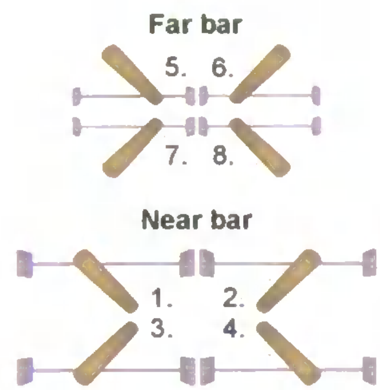
Higher-Order Interactions [6.3.6b]

Figures 8.31 and 8.32 report the pattern of means for the statistically equivalent result to the interaction reported in the main text [6.3.6a]; namely an interaction between X-Z bar position, X-Y, Y-Z cylinder orientation and mapping rule in RTs [F (1, 18) = 5.994, $p < 0.05$] and in mistakes [F (1, 18) = 6.347, $p < 0.05$]. From this perspective it can be seen how each specific lever configuration was responded to.



KEY

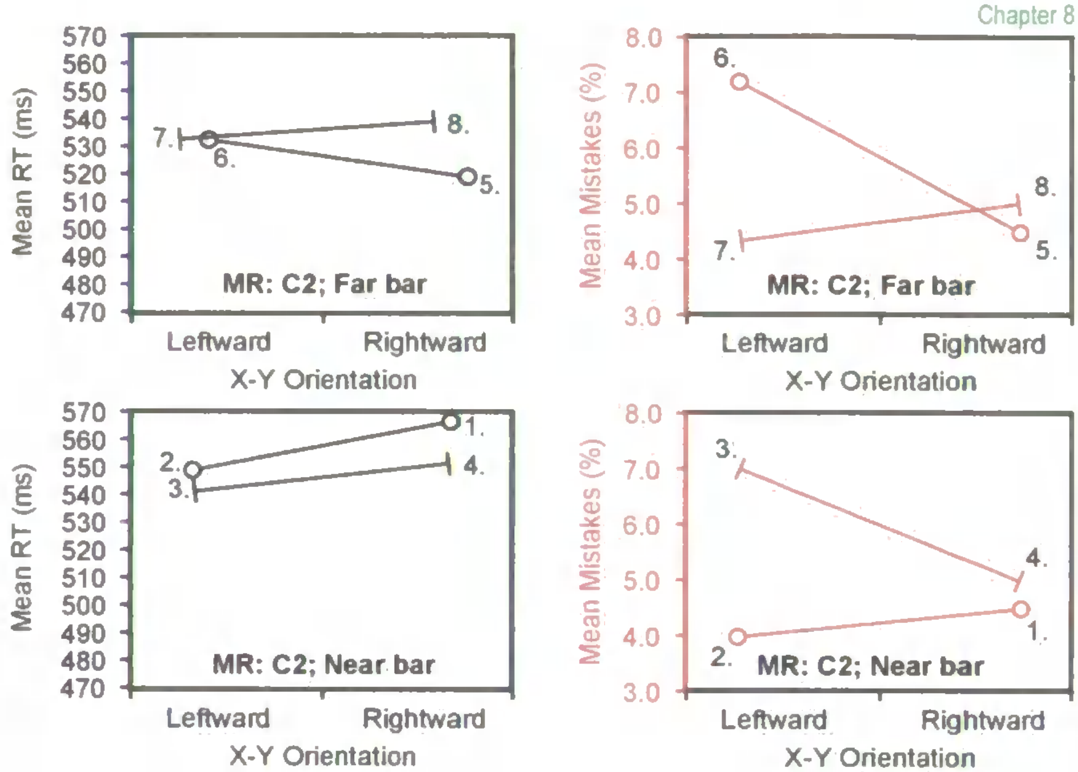
LEVERS (T1)

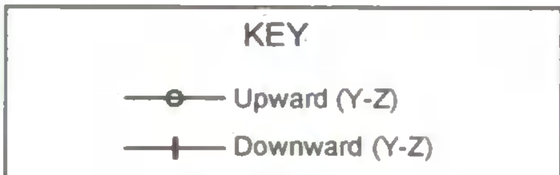


MEANS TABLE

(Lev)	MR	Bar	X-Y	Y-Z	ms	SE	%	SE
7	1	F	L	D	494	15	5.0	1.0
6	1	F	L	U	481	16	3.8	1.1
8	1	F	R	D	496	15	4.2	0.9
5	1	F	R	U	492	16	5.7	1.3
3	1	N	L	D	510	14	4.3	1.4
2	1	N	L	U	525	12	7.2	1.1
4	1	N	R	D	514	14	5.0	1.1
1	1	N	R	U	514	13	4.5	1.3

Figure 8.31 Mean RTs (black) and mean mistakes (red) as a function of X-Z bar position, X-Y, Y-Z cylinder orientation and mapping rule (n.b. MR: C1 in this figure)





MEANS TABLE

(Lev)	MR	Bar	X-Y	Y-Z	ms	SE	%	SE
7	2	F	L	D	533	15	3.8	1.0
6	2	F	L	U	533	16	6.2	1.1
8	2	F	R	D	539	15	4.5	0.9
5	2	F	R	U	519	16	3.7	1.3
3	2	N	L	D	542	14	7.0	1.4
2	2	N	L	U	550	12	4.0	1.1
4	2	N	R	D	552	14	5.0	1.1
1	2	N	R	U	567	13	4.5	1.3

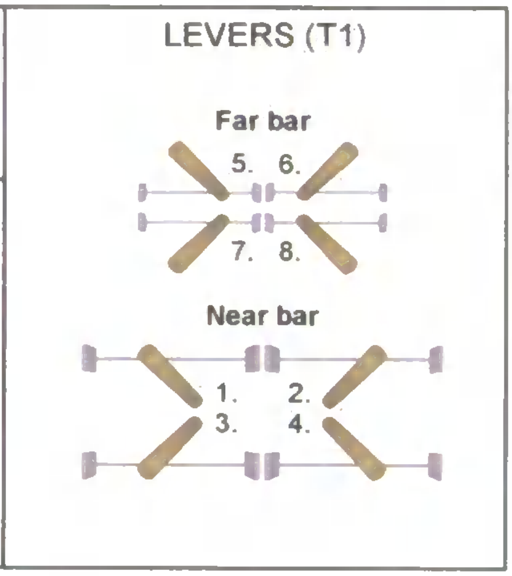
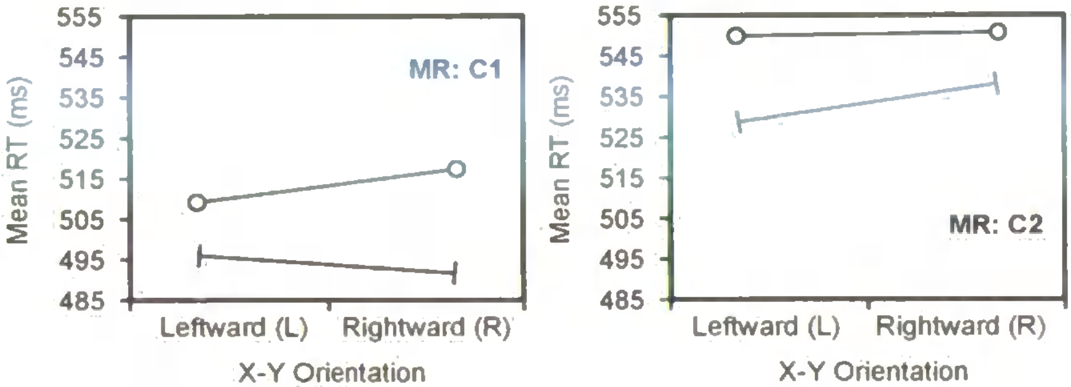


Figure 8.32 Mean RTs (black) and mean mistakes (red) as a function of X-Z bar position, X-Y, Y-Z cylinder orientation and mapping rule (n.b. MR: C2 in this figure)

Three-Way Interactions [6.3.7a]

There was an interaction that approached significance between X-Y cylinder orientation, hand of response and mapping rule in RTs [F (1, 18) = 4.310, p = 0.052] (see Figure 8.33) but not in mistakes [F (1, 18) = 1.550, p > 0.1]. The main effect of mapping rule (participants in MR: C1 responded faster than participants in MR: C2) is apparent in this interaction. In addition, for participants in MR: C1 (left response/ lever up, right response/lever down) the following pattern was observed: mean RTs for left hand responses were 8 ms faster when the cylinder component was oriented leftwards rather than rightwards in the X-Y plane, and mean RTs for right hand responses were 5 ms faster when the cylinder component was oriented rightwards rather than leftwards in the X-Y plane. For participants in MR: C2 (left response/ lever down, right response/lever up) the following pattern was observed: mean RTs for left hand responses were 1 ms faster when the cylinder component was oriented leftwards rather than rightwards in the X-Y plane, and mean RTs for right hand responses were 9 ms faster when the cylinder component was oriented leftwards rather than rightwards in the X-Y plane.



KEY

Left response

Right response

MEANS TABLE

MR	X-Y	Res	ms	SE
1	L	L	509	15
1	L	R	496	14
1	R	L	517	14
1	R	R	491	13
2	L	L	550	15
2	L	R	529	14
2	R	L	551	14
2	R	R	538	13

LEVERS (T1)

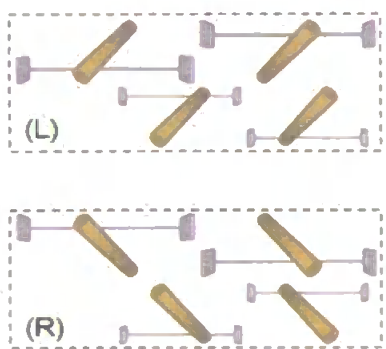
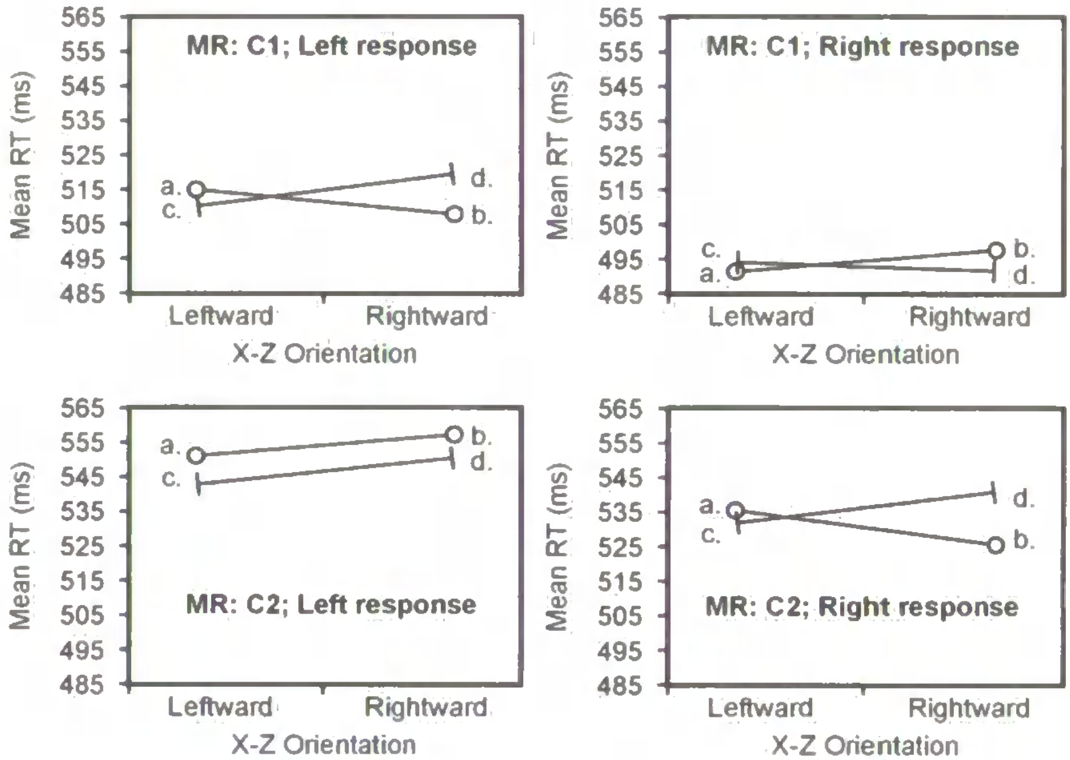
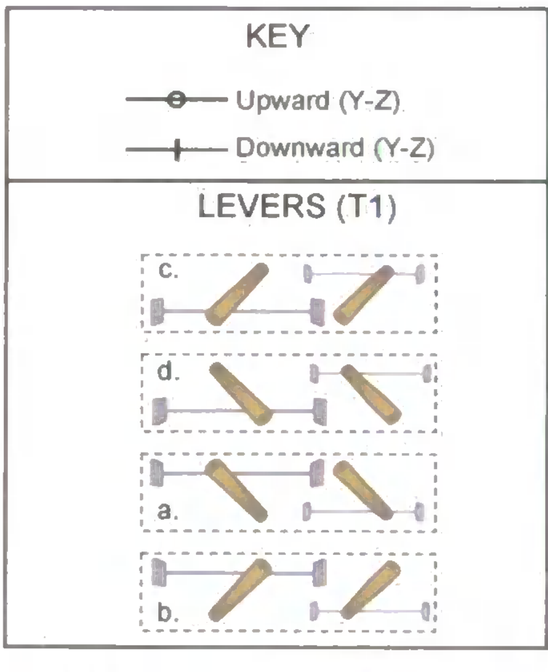


Figure 8.33 Mean RTs as a function of X-Y cylinder orientation, hand of response and mapping rule

Higher-Order Interactions [6.3.7b]

Figure 8.34 reports the pattern of means for the statistically equivalent result to the interaction reported in the main text [6.3.7a]; namely an interaction between Y-Z, X-Z cylinder orientation, hand of response and mapping rule in RTs [F (1, 18) = 4.310, p = 0.052]. From this perspective it can be seen how each specific cylinder component was responded to (but not each lever, since X-Z bar position does not feature in this interaction).





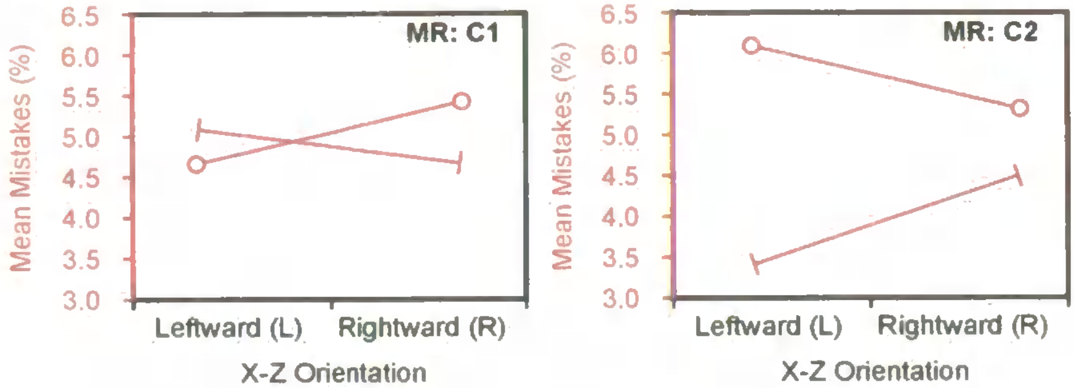
MEANS TABLE

(Lev)	MR	Y-Z	X-Z	Res	ms	SE
c	1	D	L	L	510	15
c	1	D	L	R	494	15
d	1	D	R	L	519	14
d	1	D	R	R	492	14
a	1	U	L	L	515	16
a	1	U	L	R	491	13
b	1	U	R	L	508	15
b	1	U	R	R	497	13
c	2	D	L	L	543	15
c	2	D	L	R	532	15
d	2	D	R	L	550	14
d	2	D	R	R	541	14
a	2	U	L	L	551	16
a	2	U	L	R	535	13
b	2	U	R	L	557	15
b	2	U	R	R	526	13

Figure 8.34 Mean RTs as a function of Y-Z, X-Z cylinder orientation, hand of response and mapping rule

Three-Way Interactions [6.3.8a]

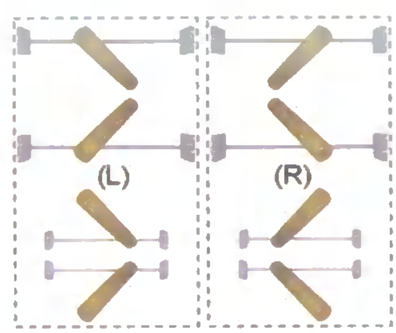
There was a significant interaction between X-Z cylinder orientation, hand of response and mapping rule in mistakes [F (1, 18) = 4.780, $p < 0.05$] (see Figure 8.35) but not in RTs [F (1, 18) = 0.763, $p > 0.1$].



KEY

Left response
Right response

LEVERS (T1)



MEANS TABLE

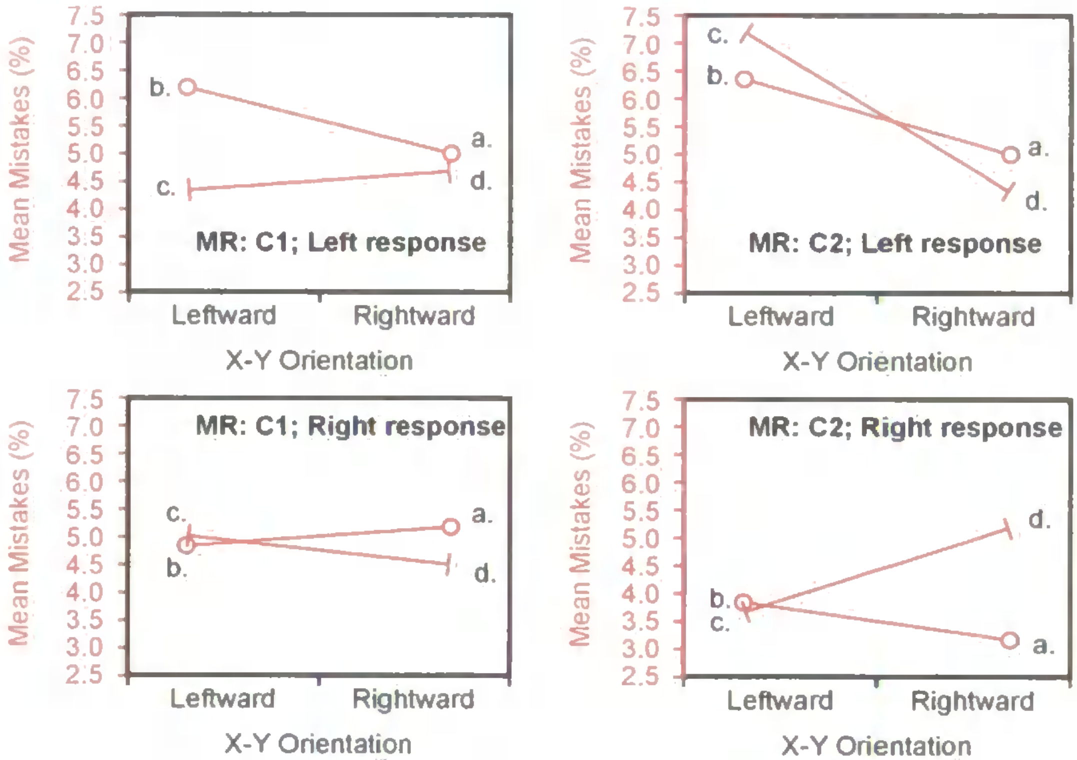
MR	X-Z	Res	%	SE
1	L	L	4.7	0.9
1	L	R	5.1	0.8
1	R	L	5.4	0.8
1	R	R	4.7	0.8
2	L	L	6.1	0.9
2	L	R	3.4	0.8
2	R	L	5.3	0.8
2	R	R	4.5	0.8

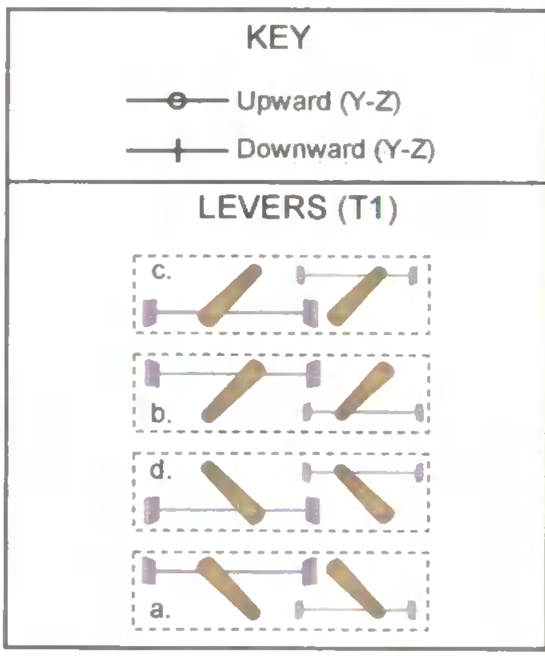
Figure 8.35 Mean mistakes as a function of X-Z cylinder orientation, hand of response and mapping rule

For participants in MR: C1 (left response/ lever up, right response/lever down) the following pattern was observed: mean mistakes for left hand responses were 0.7 % fewer when the cylinder component was oriented leftwards rather than rightwards in the X-Z plane, and mean mistakes for right hand responses were 0.4 % fewer when the cylinder component was oriented rightwards rather than leftwards in the X-Z plane. For participants in MR: C2 (left response/ lever down, right response/lever up) the following pattern was observed: mean mistakes for left hand responses were 0.8 % fewer when the cylinder component was oriented rightwards rather than leftwards in the X-Z plane, and mean mistakes for right hand responses were 1.1 % fewer when the cylinder component was oriented leftwards rather than rightwards in the X-Z plane.

Higher-Order Interactions [6.3.8b]

Figure 8.36 reports the pattern of means for the statistically equivalent result to the interaction reported in the main text [6.3.8a]; namely an interaction between X-Y, Y-Z cylinder orientation, hand of response and mapping rule in mistakes [$F(1, 18) = 4.780, p < 0.05$].





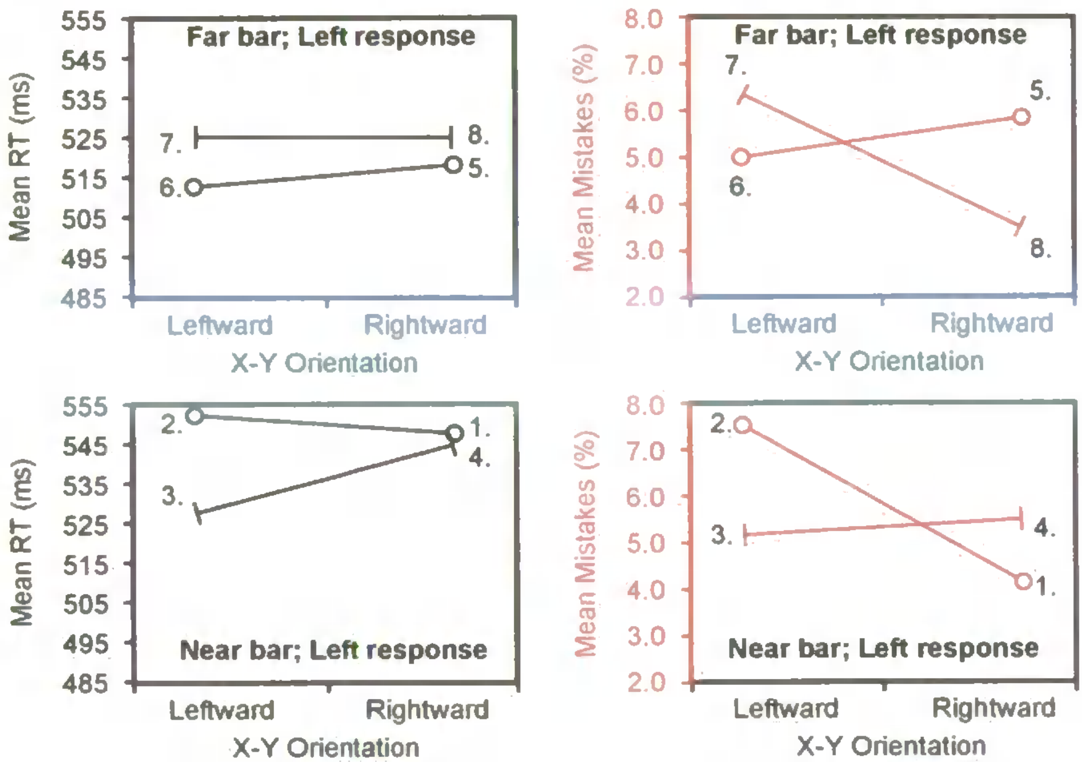
MEANS TABLE

(Lev)	MR	X-Y	Y-Z	Res	%	SE
c	1	L	D	L	4.3	1.2
c	1	L	D	R	5.0	1.0
b	1	L	U	L	6.2	1.4
b	1	L	U	R	4.8	1.0
d	1	R	D	L	4.7	0.8
d	1	R	D	R	4.5	1.2
a	1	R	U	L	5.0	1.3
a	1	R	U	R	5.2	1.1
c	2	L	D	L	7.2	1.2
c	2	L	D	R	3.7	1.0
b	2	L	U	L	6.3	1.4
b	2	L	U	R	3.8	1.0
d	2	R	D	L	4.3	0.8
d	2	R	D	R	5.2	1.2
a	2	R	U	L	5.0	1.3
a	2	R	U	R	3.2	1.1

Figure 8.36 Mean mistakes as a function of X-Y, Y-Z cylinder orientation, hand of response and mapping rule

Higher Order Interactions [6.3.9b ✓]

Figures 8.37 and 8.38 report the pattern of means for the statistically equivalent result to the interaction reported in the main text [6.3.9a]; namely an interaction between X-Z bar position, X-Y, Y-Z cylinder orientation and hand of response in both RTs [F (1, 18) = 12.570, p < 0.005] and mistakes [F (1, 18) = 15.060, p < 0.005]. From this perspective it can be seen how each specific lever was responded to.



KEY

MEANS TABLE

(Lev)	Bar	X-Y	Y-Z	Res	ms	SE	%	SE
7	F	L	D	L	525	14	6.3	1.1
6	F	L	U	L	513	12	5.0	1.2
8	F	R	D	L	525	13	3.5	0.7
5	F	R	U	L	518	12	5.8	1.5
3	N	L	D	L	528	11	5.2	1.1
2	N	L	U	L	552	13	7.5	1.2
4	N	R	D	L	545	11	5.5	0.9
1	N	R	U	L	548	12	4.2	1.1

LEVERS (T1)

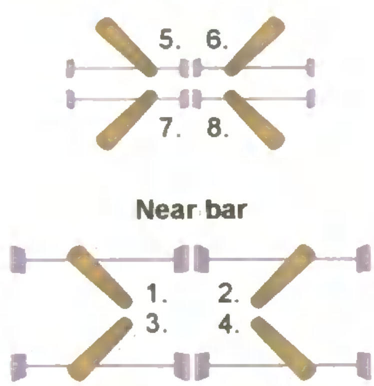
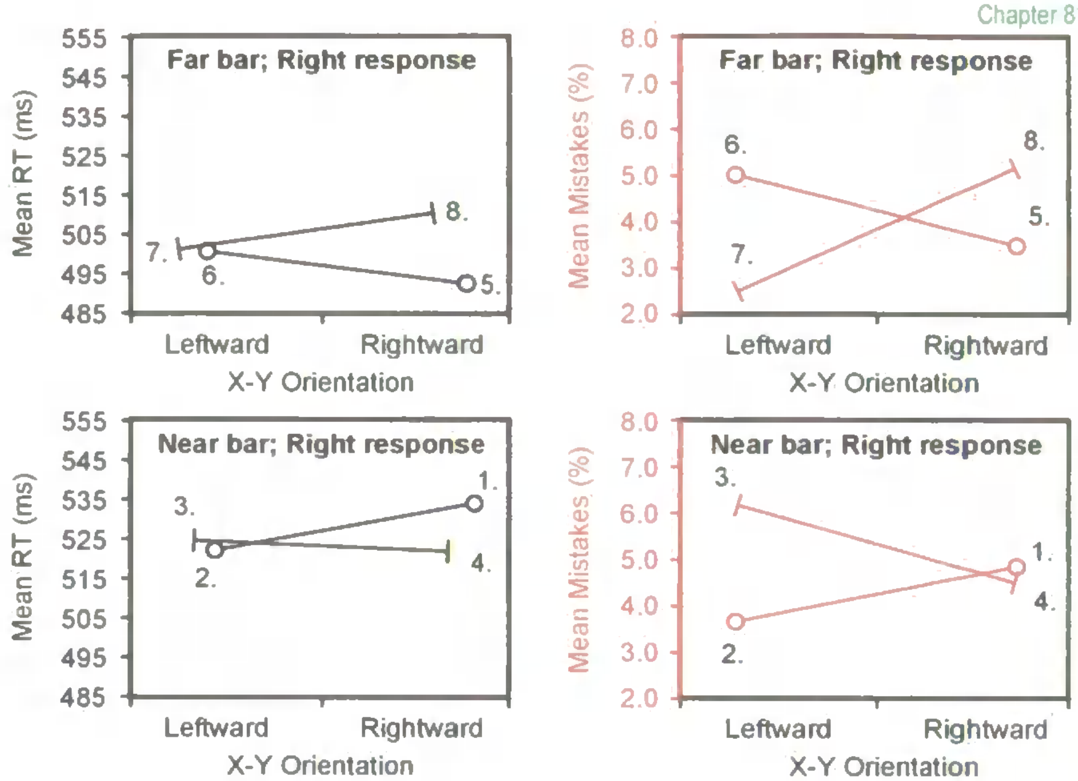


Figure 8.37 Mean RTs (black) and mean mistakes (red) as a function of X-Z bar position, X-Y, Y-Z cylinder orientation and hand of response (n.b. left responses in this figure)



KEY

Upward (Y-Z)

Downward (Y-Z)

MEANS TABLE

(Lev)	Bar	X-Y	Y-Z	Res	ms	SE	%	SE
7	F	L	D	R	501	9	2.5	0.7
6	F	L	U	R	501	13	5.0	0.9
8	F	R	D	R	510	9	5.2	1.0
5	F	R	U	R	493	13	3.5	0.9
3	N	L	D	R	525	14	6.2	1.1
2	N	L	U	R	522	8	3.7	0.9
4	N	R	D	R	522	13	4.5	1.0
1	N	R	U	R	534	9	4.8	1.0

LEVERS (T1)

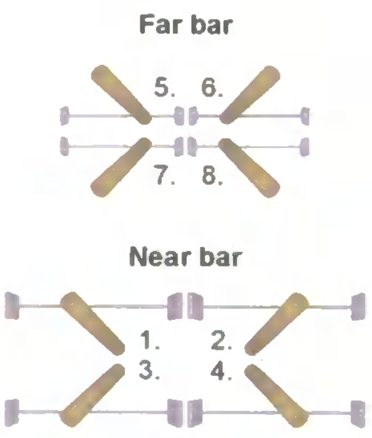
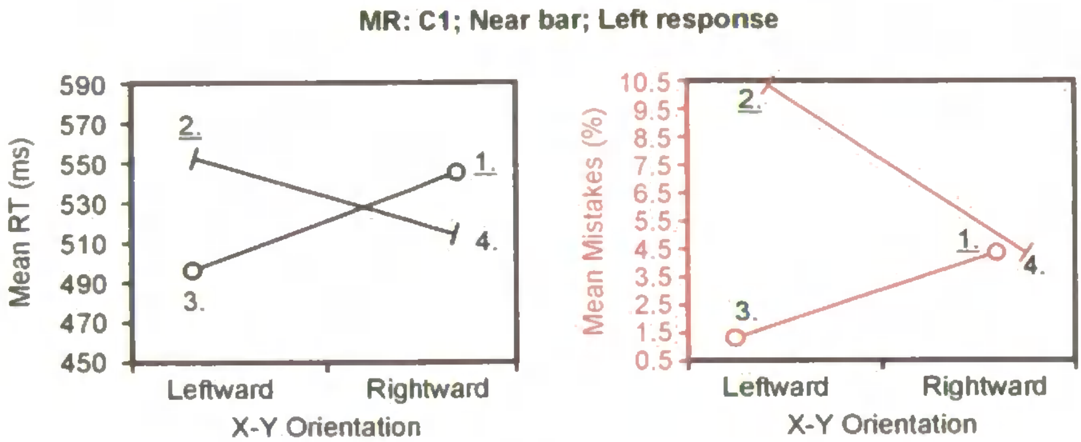


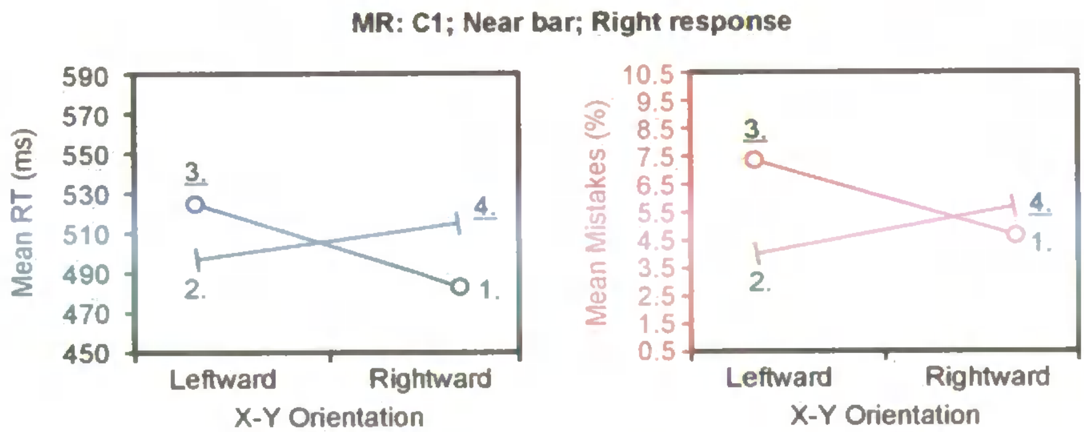
Figure 8.38 Mean RTs (black) and mean mistakes (red) as a function of X-Z bar position, X-Y, Y-Z cylinder orientation and hand of response (n.b. right responses in this figure)

Higher Order Interactions [6.3.10b ✗]

Figures 8.39 – 8.42 report the pattern of means for the statistically equivalent result to the interaction reported in the main text [6.3.10a]; namely an interaction between mapping rule, X-Z bar position, X-Y, Y-Z cylinder orientation and hand of response in both RTs [F (1, 18) = 17.683, $p < 0.005$] and in mistakes [F (1, 18) = 47.234, p <

0.001]. From this perspective it can be seen how each specific lever was responded to.





MEANS TABLE

(Lev)	MR	Bar	X-Y	X-Z	Res	ms	SE	%	SE
3	C1	N	L	L	L	496	15	1.3	1.6
3	C1	N	L	L	R	524	20	7.3	1.5
2	C1	N	L	R	L	552	18	10.3	1.7
2	C1	N	L	R	R	497	11	4.0	1.2
1	C1	N	R	L	L	545	17	4.3	1.6
1	C1	N	R	L	R	484	13	4.7	1.5
4	C1	N	R	R	L	514	15	4.3	1.3
4	C1	N	R	R	R	515	18	5.7	1.4

LEVERS (T1- T2)

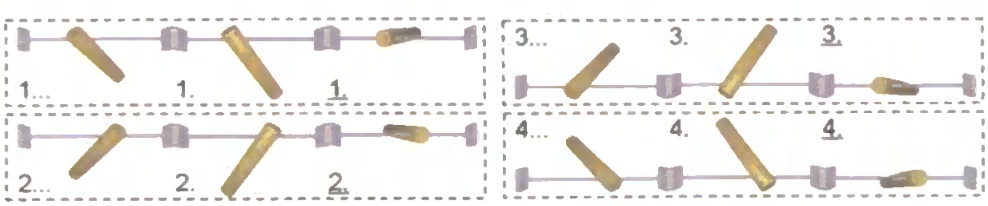
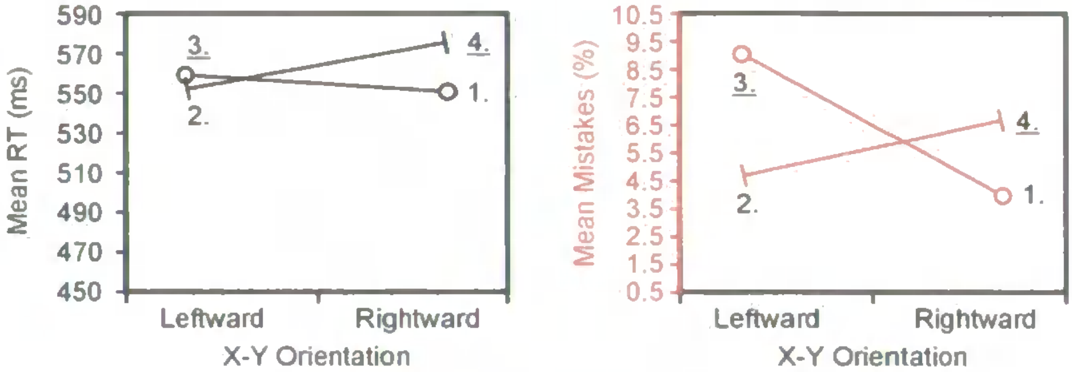
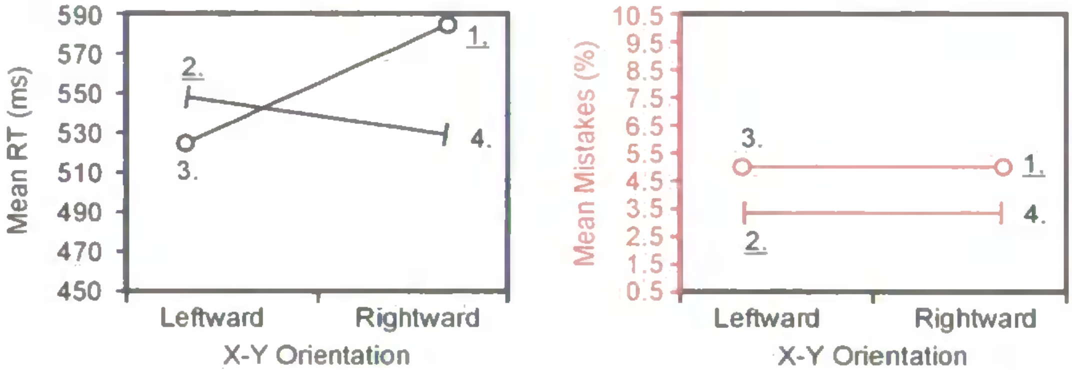


Figure 8.39 Mean RTs (black) and mean mistakes (red) as a function of X-Z bar position (n.b. near in this figure), X-Y, X-Z cylinder orientation, hand of response and mapping rule (n.b. MR: C1 in this figure)

MR: C2; Near bar; Left response



MR: C2; Near bar; Right response



KEY

- Leftwards (X-Z)
- Rightwards (X-Z)

MEANS TABLE

(Lev)	MR	Bar	X-Y	X-Z	Res	ms	SE	%	SE
3	C2	N	L	L	L	559	15	9.0	1.6
3	C2	N	L	L	R	525	20	5.0	1.5
2	C2	N	L	R	L	552	18	4.7	1.7
2	C2	N	L	R	R	548	11	3.3	1.2
1	C2	N	R	L	L	551	17	4.0	1.6
1	C2	N	R	L	R	584	13	5.0	1.5
4	C2	N	R	R	L	575	15	6.7	1.3
4	C2	N	R	R	R	529	18	3.3	1.4

LEVERS (T1- T2)

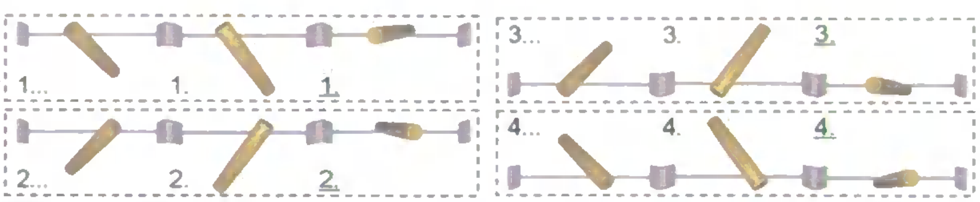
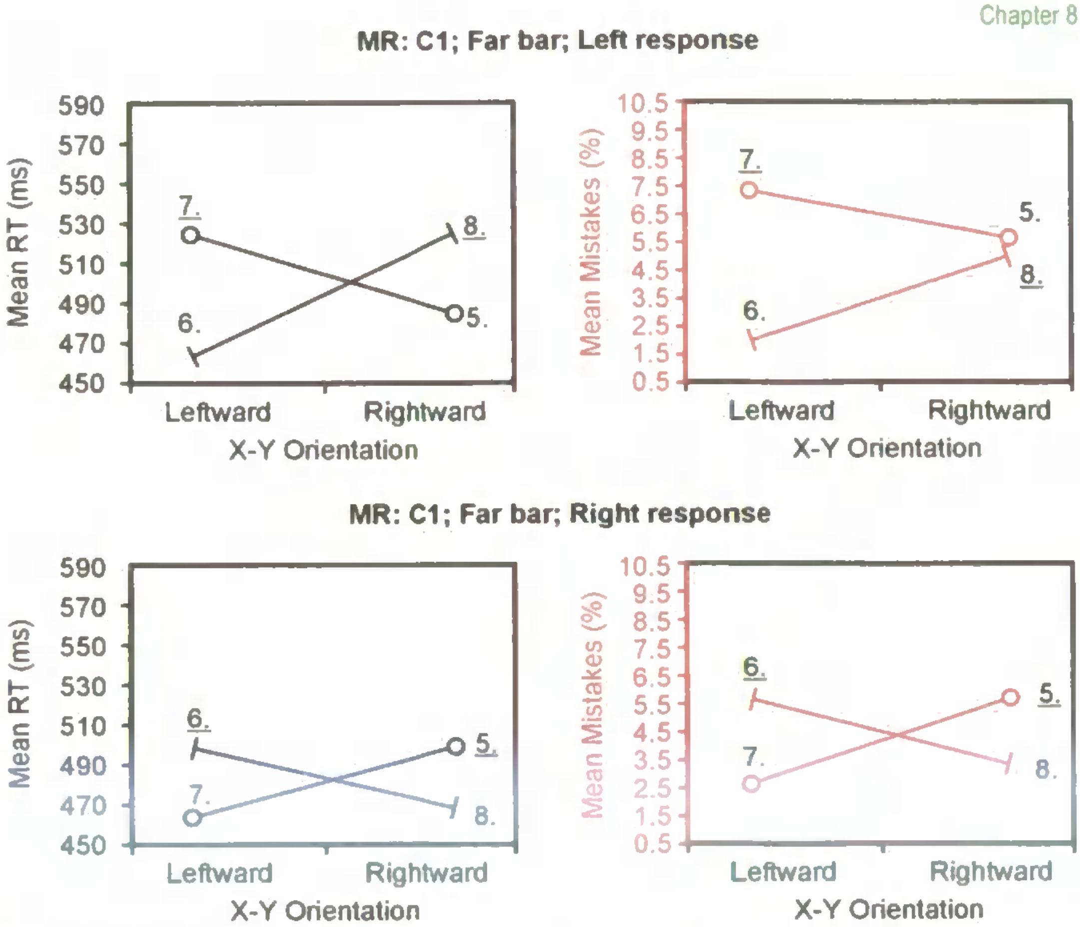


Figure 8.40 Mean RTs (black) and mean mistakes (red) as a function of X-Z bar position (n.b. near in this figure), X-Y, X-Z cylinder orientation, hand of response and mapping rule (n.b. MR: C2 in this figure)



KEY

- —o— Leftwards (X-Z)
- —+— Rightwards (X-Z)

MEANS TABLE

(Lev)	MR	Bar	X-Y	X-Z	Res	ms	SE	%	SE
7	C1	F	L	L	L	524	19	7.3	1.6
7	C1	F	L	L	R	464	13	2.7	1.0
6	C1	F	L	R	L	463	16	2.0	1.7
6	C1	F	L	R	R	498	19	5.7	1.2
5	C1	F	R	L	L	485	17	5.7	2.1
5	C1	F	R	L	R	499	18	5.7	1.3
8	C1	F	R	R	L	525	18	5.0	1.0
8	C1	F	R	R	R	468	13	3.3	1.4

LEVERS (T1- T2)

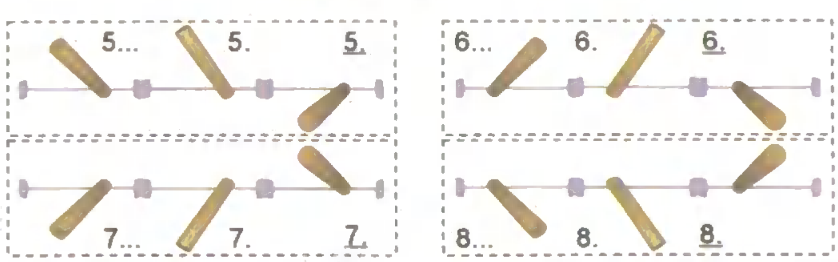
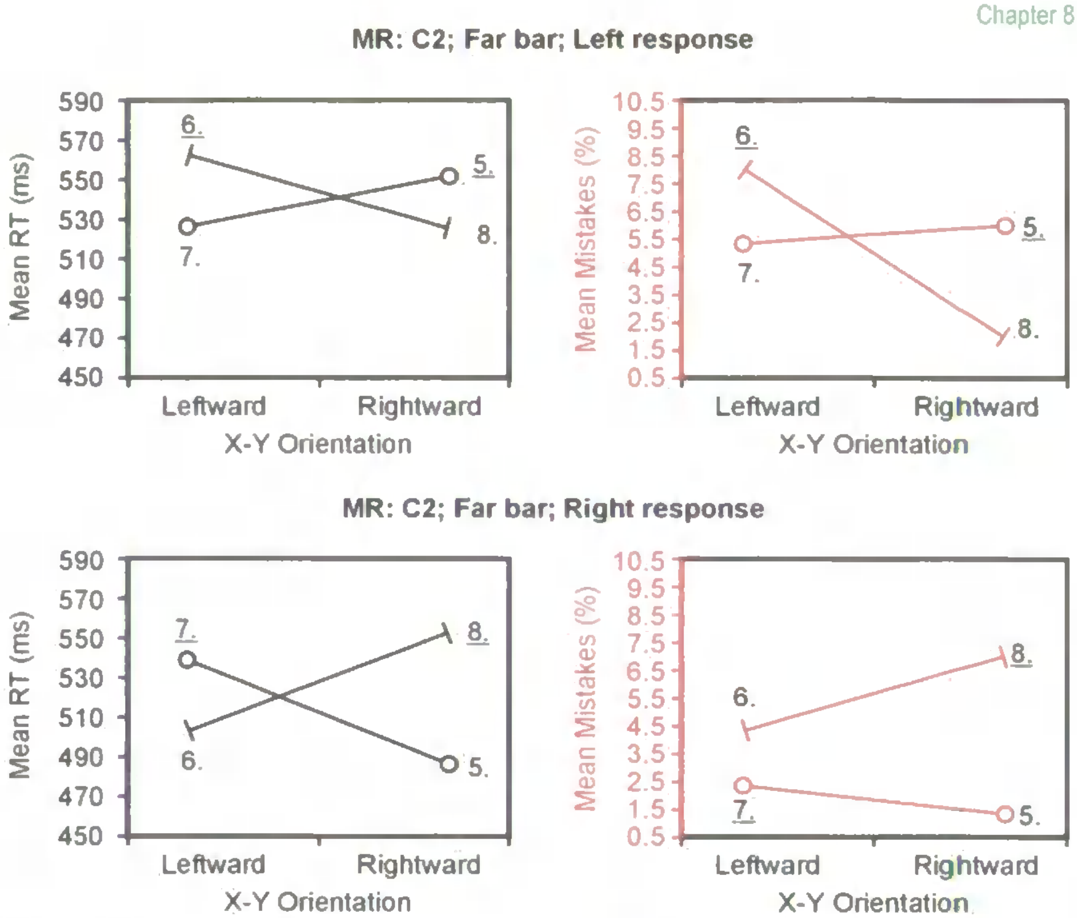


Figure 8.41 Mean RTs (black) and mean mistakes (red) as a function of X-Z bar position (n.b. far in this figure), X-Y, X-Z cylinder orientation, hand of response and mapping rule (n.b. MR: C1 in this figure)



MEANS TABLE

(Lev)	MR	Bar	X-Y	X-Z	Res	ms	SE	%	SE
7	C2	F	L	L	L	527	19	5.3	1.6
7	C2	F	L	L	R	539	13	2.3	1.0
6	C2	F	L	R	L	562	16	8.0	1.7
6	C2	F	L	R	R	503	19	4.3	1.2
5	C2	F	R	L	L	551	17	6.0	2.1
5	C2	F	R	L	R	487	18	1.3	1.3
8	C2	F	R	R	L	525	18	2.0	1.0
8	C2	F	R	R	R	553	13	7.0	1.4

LEVERS (T1- T2)

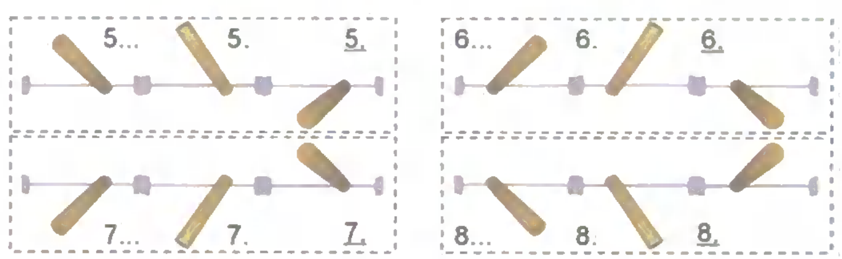


Figure 8.42 Mean RTs (black) and mean mistakes (red) as a function of X-Z bar position (n.b. far in this figure), X-Y, X-Z cylinder orientation, hand of response and mapping rule (n.b. MR: C2 in this figure)

The overwhelming pattern supported an advantage for short rather than long movements of each specific lever configuration (levers 1-8), regardless of whether this was effected by an up or down movement (i.e. a left or right response). Furthermore, upon closer inspection (see section 6.4.3), it appeared that there was a clearly identifiable gradation of effect size corresponding to the actual physical difficulty of moving particular lever configurations.

8.3 Appendix 3 (Means tables)

Table 8.26 Experiment 4.1- Mean RTs (ms) and standard errors (SE) for result [4.1.13]

MR1 (C)	MR2 (C)	Response Effector	X-Y Line Orientation	✓ (ms)	SE
1	1	Hands	Leftwards	467	18
1	1	Hands	Rightwards	468	19
1	1	Feet	Leftwards	505	23
1	1	Feet	Rightwards	502	22
1	2	Hands	Leftwards	436	18
1	2	Hands	Rightwards	430	19
1	2	Feet	Leftwards	473	23
1	2	Feet	Rightwards	474	22
2	1	Hands	Leftwards	437	18
2	1	Hands	Rightwards	438	19
2	1	Feet	Leftwards	500	23
2	1	Feet	Rightwards	504	22
2	2	Hands	Leftwards	435	18
2	2	Hands	Rightwards	437	19
2	2	Feet	Leftwards	493	23
2	2	Feet	Rightwards	489	22

Table 8.27 Experiment 4.1- Mean mistakes (%) and standard errors (SE) for result [4.1.14]

MR1 (C)	Line Location	X-Y Line Orientation	Spatial Respons	X (%)	SE
1	Left	Leftwards	Left	2.1	0.5
1	Left	Leftwards	Right	5.3	0.9
1	Left	Rightwards	Left	1.5	0.3
1	Left	Rightwards	Right	3.9	0.8
1	Centre	Leftwards	Left	2.9	0.7
1	Centre	Leftwards	Right	1.9	0.4
1	Centre	Rightwards	Left	2.5	0.5
1	Centre	Rightwards	Right	2.5	0.7
1	Right	Leftwards	Left	4.1	1.0
1	Right	Leftwards	Right	2.8	0.7
1	Right	Rightwards	Left	4.7	1.0
1	Right	Rightwards	Right	0.8	0.4
2	Left	Leftwards	Left	1.4	0.5
2	Left	Leftwards	Right	3.6	0.9
2	Left	Rightwards	Left	0.5	0.3
2	Left	Rightwards	Right	4.5	0.8
2	Centre	Leftwards	Left	1.0	0.7
2	Centre	Leftwards	Right	1.5	0.4
2	Centre	Rightwards	Left	2.2	0.5
2	Centre	Rightwards	Right	1.7	0.7
2	Right	Leftwards	Left	3.7	1.0
2	Right	Leftwards	Right	1.1	0.7
2	Right	Rightwards	Left	1.6	1.0
2	Right	Rightwards	Right	0.7	0.4

Table 8.28 Experiment 4.3- Mean RTs (ms) and standard errors (SE) for result [5.3.12]

MR1 (C)	Response Effector	X-Y Cylinder Orientation	Spatial Response	✔ (ms)	SE
1	Feet	Leftwards	Left	524	16
1	Feet	Leftwards	Right	519	18
1	Feet	Rightwards	Left	523	17
1	Feet	Rightwards	Right	522	19
1	Hands	Leftwards	Left	459	13
1	Hands	Leftwards	Right	476	14
1	Hands	Rightwards	Left	464	12
1	Hands	Rightwards	Right	469	15
2	Feet	Leftwards	Left	537	16
2	Feet	Leftwards	Right	544	18
2	Feet	Rightwards	Left	542	17
2	Feet	Rightwards	Right	539	19
2	Hands	Leftwards	Left	484	13
2	Hands	Leftwards	Right	501	14
2	Hands	Rightwards	Left	481	12
2	Hands	Rightwards	Right	512	15

Table 8.29 Experiment 5.3- Mean RTs (ms) and standard errors (SE) for result [5.3.13]

MR1 (C)	MR2 (C)	Response Effector	X-Y Cylinder Orientation	Spatial Response	✓ (ms)	SE
1	1	Feet	Leftwards	Left	501	23
1	1	Feet	Leftwards	Right	488	26
1	1	Feet	Rightwards	Left	503	23
1	1	Feet	Rightwards	Right	487	26
1	1	Hands	Leftwards	Left	462	19
1	1	Hands	Leftwards	Right	469	20
1	1	Hands	Rightwards	Left	467	17
1	1	Hands	Rightwards	Right	469	21
1	2	Feet	Leftwards	Left	546	23
1	2	Feet	Leftwards	Right	550	26
1	2	Feet	Rightwards	Left	543	23
1	2	Feet	Rightwards	Right	556	26
1	2	Hands	Leftwards	Left	457	19
1	2	Hands	Leftwards	Right	483	20
1	2	Hands	Rightwards	Left	462	17
1	2	Hands	Rightwards	Right	469	21
2	1	Feet	Leftwards	Left	523	23
2	1	Feet	Leftwards	Right	524	26
2	1	Feet	Rightwards	Left	522	23
2	1	Feet	Rightwards	Right	524	26
2	1	Hands	Leftwards	Left	480	19
2	1	Hands	Leftwards	Right	498	20
2	1	Hands	Rightwards	Left	480	17
2	1	Hands	Rightwards	Right	508	21
2	2	Feet	Leftwards	Left	552	23
2	2	Feet	Leftwards	Right	564	26
2	2	Feet	Rightwards	Left	563	23
2	2	Feet	Rightwards	Right	554	26
2	2	Hands	Leftwards	Left	488	19
2	2	Hands	Leftwards	Right	504	20
2	2	Hands	Rightwards	Left	481	17
2	2	Hands	Rightwards	Right	515	21

Table 8.30 Experiment 5.3- Mean mistakes (%) and standard errors (SE) for result [5.3.14]

MR1 (C)	MR2 (C)	Response Effector	X-Z Cylinder Orientation	Spatial Response	X(%)	SE
1	1	Feet	Leftwards	Left	7.32	1.63
1	1	Feet	Leftwards	Right	5.23	2.21
1	1	Feet	Rightwards	Left	7.17	1.21
1	1	Feet	Rightwards	Right	7.32	1.51
1	1	Hands	Leftwards	Left	3.56	1.08
1	1	Hands	Leftwards	Right	8.39	2.50
1	1	Hands	Rightwards	Left	8.86	1.43
1	1	Hands	Rightwards	Right	4.74	1.51
1	2	Feet	Leftwards	Left	5.23	1.63
1	2	Feet	Leftwards	Right	8.07	2.21
1	2	Feet	Rightwards	Left	7.95	1.21
1	2	Feet	Rightwards	Right	5.92	1.51
1	2	Hands	Leftwards	Left	4.26	1.08
1	2	Hands	Leftwards	Right	10.80	2.50
1	2	Hands	Rightwards	Left	6.80	1.43
1	2	Hands	Rightwards	Right	8.74	1.51
2	1	Feet	Leftwards	Left	4.49	1.63
2	1	Feet	Leftwards	Right	7.40	2.21
2	1	Feet	Rightwards	Left	4.68	1.21
2	1	Feet	Rightwards	Right	5.90	1.51
2	1	Hands	Leftwards	Left	3.09	1.08
2	1	Hands	Leftwards	Right	7.02	2.50
2	1	Hands	Rightwards	Left	5.29	1.43
2	1	Hands	Rightwards	Right	5.97	1.51
2	2	Feet	Leftwards	Left	3.23	1.63
2	2	Feet	Leftwards	Right	6.11	2.21
2	2	Feet	Rightwards	Left	2.85	1.21
2	2	Feet	Rightwards	Right	4.33	1.51
2	2	Hands	Leftwards	Left	1.99	1.08
2	2	Hands	Leftwards	Right	9.01	2.50
2	2	Hands	Rightwards	Left	4.57	1.43
2	2	Hands	Rightwards	Right	3.07	1.51

8.4 Appendix 4 (Overall experimental means)

Table 8.31 - Overall experimental means for Experiment 3.1

				A by M		A by P	
mr	loc	ori	res	mean (ms)	mean (%)	mean (ms)	mean (%)
1	L	L	L	726.23	1.061	722.649	1.061
1	L	L	R	729.502	5.758	749.61	2.121
1	L	R	L	723.017	2.879	714.888	2.879
1	L	R	R	731.242	5.606	743.397	2.879
1	R	L	L	759.311	4.697	758.661	4.697
1	R	L	R	727.03	2.879	736.999	1.212
1	R	R	L	749.518	5.152	744.071	5.152
1	R	R	R	702.094	2.879	716.185	1.364
2	L	L	L	714.855	2.121	737.825	2.121
2	L	L	R	757.447	2.121	752.961	5.758
2	L	R	L	718.424	1.97	732.119	1.97
2	L	R	R	747.781	2.879	738.649	5.606
2	R	L	L	733.645	3.333	758.239	3.333
2	R	L	R	737.106	1.212	747.259	2.879
2	R	R	L	740.913	3.03	765.909	3.03
2	R	R	R	720.089	1.364	708.165	2.879

Table 8.32 - Overall experimental means for Experiment 4.1 (MR1: C1)

mr1	mr2	eff	loc	ori	res	mean (ms)	mean (%)
1	1	H	L	L	L	459.924	4.643
1	1	H	L	L	R	475.018	5.833
1	1	H	L	R	L	453.78	2.917
1	1	H	L	R	R	471.751	5.417
1	1	H	C	L	L	470.439	4.181
1	1	H	C	L	R	455.125	3.75
1	1	H	C	R	L	468.524	4.21
1	1	H	C	R	R	469.291	4.167
1	1	H	R	L	L	478.47	5.833
1	1	H	R	L	R	460.456	2.5
1	1	H	R	R	L	484.923	6.681
1	1	H	R	R	R	458.627	1.667
1	1	F	L	L	L	498.028	1.681
1	1	F	L	L	R	533.015	5
1	1	F	L	R	L	498.951	1.25
1	1	F	L	R	R	512.126	5.417
1	1	F	C	L	L	507.356	1.667
1	1	F	C	L	R	478.381	1.667
1	1	F	C	R	L	516.364	0.833
1	1	F	C	R	R	487.443	2.126
1	1	F	R	L	L	525.153	3.75
1	1	F	R	L	R	490.445	3.75
1	1	F	R	R	L	524.221	5.417
1	1	F	R	R	R	470.075	0.417
1	2	H	L	L	L	429.86	1.667
1	2	H	L	L	R	439.424	7.083
1	2	H	L	R	L	432.318	1.695
1	2	H	L	R	R	437.125	2.112
1	2	H	C	L	L	430.279	4.239
1	2	H	C	L	R	429.101	1.25
1	2	H	C	R	L	429.787	2.5
1	2	H	C	R	R	417.658	2.5
1	2	H	R	L	L	450.331	2.976
1	2	H	R	L	R	434.815	3.75
1	2	H	R	R	L	442.246	3.75
1	2	H	R	R	R	418.329	0.417
1	2	F	L	L	L	458.591	0.417
1	2	F	L	L	R	500.733	3.348
1	2	F	L	R	L	463.02	0
1	2	F	L	R	R	489.354	2.543
1	2	F	C	L	L	470.199	1.667
1	2	F	C	L	R	462.94	0.833
1	2	F	C	R	L	473.581	2.5
1	2	F	C	R	R	467.565	1.25
1	2	F	R	L	L	495.577	3.75
1	2	F	R	L	R	447.811	1.279
1	2	F	R	R	L	497.346	2.917
1	2	F	R	R	R	451.337	0.862

Table 8.33 - Overall experimental means for Experiment 4.1 (MR1: C2)

mr1	mr2	eff	loc	ori	res	mean (ms)	mean (%)
2	1	H	L	L	L	421.475	1.695
2	1	H	L	L	R	452.256	5.417
2	1	H	L	R	L	425.726	1.25
2	1	H	L	R	R	457.063	5
2	1	H	C	L	L	430.57	0.833
2	1	H	C	L	R	435.294	2.917
2	1	H	C	R	L	427.35	4.167
2	1	H	C	R	R	434.865	3.333
2	1	H	R	L	L	446.224	3.333
2	1	H	R	L	R	438.901	2.5
2	1	H	R	R	L	449.779	1.667
2	1	H	R	R	R	432.213	2.083
2	1	F	L	L	L	484.641	1.25
2	1	F	L	L	R	514.939	3.393
2	1	F	L	R	L	484.989	0
2	1	F	L	R	R	524.665	3.75
2	1	F	C	L	L	502.854	0.848
2	1	F	C	L	R	491.754	1.25
2	1	F	C	R	L	496.208	1.25
2	1	F	C	R	R	497.223	1.264
2	1	F	R	L	L	520.315	3.779
2	1	F	R	L	R	486.762	0.431
2	1	F	R	R	L	530.819	2.083
2	1	F	R	R	R	488.353	0.417
2	2	H	L	L	L	428.636	1.25
2	2	H	L	L	R	451.728	3.75
2	2	H	L	R	L	432.406	0
2	2	H	L	R	R	449.414	6.695
2	2	H	C	L	L	427.992	1.25
2	2	H	C	L	R	429.968	0.417
2	2	H	C	R	L	430.123	2.5
2	2	H	C	R	R	432.08	1.25
2	2	H	R	L	L	442.989	5
2	2	H	R	L	R	428.268	0.417
2	2	H	R	R	L	445.26	2.098
2	2	H	R	R	R	432.08	0
2	2	F	L	L	L	476.367	1.25
2	2	F	L	L	R	516.901	1.668
2	2	F	L	R	L	471.588	0.833
2	2	F	L	R	R	515.312	2.5
2	2	F	C	L	L	487.781	1.25
2	2	F	C	L	R	486.594	1.25
2	2	F	C	R	L	485.041	0.833
2	2	F	C	R	R	476.541	0.833
2	2	F	R	L	L	517.094	2.5
2	2	F	R	L	R	474.504	1.25
2	2	F	R	R	L	515.265	0.417
2	2	F	R	R	R	468.149	0.417

Table 8.34 - Overall experimental means for Experiment 4.2

mr	soa (ms)	ori	res	mean (ms)	mean (%)
1	50	L	L	438.176	4
1	50	L	R	423.872	4.2
1	50	R	L	444.302	4.6
1	50	R	R	422.626	3.4
1	100	L	L	428.804	3.8
1	100	L	R	434.933	5.8
1	100	R	L	438.688	6.2
1	100	R	R	429.954	6.6
2	50	L	L	424.144	0.8
2	50	L	R	433.146	2.4
2	50	R	L	427.382	3
2	50	R	R	426.72	1.2
2	100	L	L	425.872	2.4
2	100	L	R	413.57	3.8
2	100	R	L	434.616	2.2
2	100	R	R	412.176	2.4

Table 8.35 - Overall experimental means for Experiment 4.3

soa (ms)	ori	res	mean (ms)	mean (%)
0	L	L	473.11	1.509
0	L	R	455.459	3.145
0	R	L	472.538	2.39
0	R	R	465.334	3.396
400	L	L	441.385	1.144
400	L	R	439.906	2.893
400	R	L	441.612	1.006
400	R	R	445.322	3.019
800	L	L	443.575	1.635
800	L	R	427.633	1.132
800	R	L	443.942	1.635
800	R	R	423.047	1.635

Table 8.36 - Overall experimental means for Experiment 5.1

mr	ori (xy)	ori (xz)	res	mean (ms)	mean (%)
1	L	L	L	490.696	6.727
1	L	L	R	489.63	7.455
1	L	R	L	503.302	8.545
1	L	R	R	475.188	6.545
1	R	L	L	488.806	5.091
1	R	L	R	486.795	9.091
1	R	R	L	496.49	7.091
1	R	R	R	475.665	8.545
2	L	L	L	451.394	4.545
2	L	L	R	463.569	10
2	L	R	L	464.592	7.636
2	L	R	R	459.005	7.273
2	R	L	L	458.603	5.818
2	R	L	R	469.434	11.818
2	R	R	L	463.947	6.909
2	R	R	R	467.715	8.727

Table 8.37 - Overall experimental means for Experiment 5.2

mr	ori (xy)	ori (xz)	res	mean (ms)	mean (%)
1	L	L	L	479.81	4.4
1	L	L	R	497.54	8.8
1	L	R	L	492.653	7.4
1	L	R	R	473.108	6.4
1	R	L	L	481.619	3.6
1	R	L	R	494.286	8.6
1	R	R	L	486.881	5
1	R	R	R	477.129	4.4
2	L	L	L	488.317	4.8
2	L	L	R	499.733	5
2	L	R	L	499.091	7.4
2	L	R	R	492.79	5
2	R	L	L	485.115	2.6
2	R	L	R	505.643	4.4
2	R	R	L	498.687	4
2	R	R	R	491.258	7

Table 8.38 - Overall experimental means for Experiment 5.3 (MR1: C1)

mr1	mr2	eff	ori (xy)	ori (xz)	res	mean (ms)	mean (%)
1	1	H	L	L	L	462.909	2.978
1	1	H	L	L	R	476.895	11.436
1	1	H	L	R	L	460.321	7.974
1	1	H	L	R	R	460.516	3.873
1	1	H	R	L	L	447.08	4.152
1	1	H	R	L	R	476.782	5.346
1	1	H	R	R	L	486.296	9.749
1	1	H	R	R	R	461.173	5.606
1	1	F	L	L	L	492.62	10.228
1	1	F	L	L	R	489.089	5.28
1	1	F	L	R	L	509.065	5.41
1	1	F	L	R	R	486.141	7.79
1	1	F	R	L	L	491.11	4.42
1	1	F	R	L	R	483.687	5.171
1	1	F	R	R	L	515.464	8.926
1	1	F	R	R	R	490.969	6.848
1	2	H	L	L	L	447.607	5.071
1	2	H	L	L	R	494.98	11.672
1	2	H	L	R	L	466.717	6.119
1	2	H	L	R	R	471.709	9.693
1	2	H	R	L	L	452.311	3.452
1	2	H	R	L	R	473.28	9.933
1	2	H	R	R	L	470.716	7.476
1	2	H	R	R	R	465.677	7.791
1	2	F	L	L	L	545.008	4.982
1	2	F	L	L	R	543.141	7.344
1	2	F	L	R	L	547.75	6.801
1	2	F	L	R	R	555.919	6.79
1	2	F	R	L	L	531.71	5.48
1	2	F	R	L	R	556.113	8.803
1	2	F	R	R	L	554.583	9.104
1	2	F	R	R	R	556.741	5.059

Table 8.39 - Overall experimental means for Experiment 5.3 (MR1: C2)

mr1	mr2	eff	ori (xy)	ori (xz)	res	mean (ms)	mean (%)
2	1	H	L	L	L	476.371	3.826
2	1	H	L	L	R	500.061	4.698
2	1	H	L	R	L	484.501	4.834
2	1	H	L	R	R	496.845	6.039
2	1	H	R	L	L	466.53	2.359
2	1	H	R	L	R	511.784	9.343
2	1	H	R	R	L	494.312	5.754
2	1	H	R	R	R	505.021	5.903
2	1	F	L	L	L	517.817	5.256
2	1	F	L	L	R	532.211	7.623
2	1	F	L	R	L	527.332	3.592
2	1	F	L	R	R	516.558	6.844
2	1	F	R	L	L	517	3.717
2	1	F	R	L	R	528.962	7.169
2	1	F	R	R	L	527.205	5.769
2	1	F	R	R	R	518.827	4.959
2	2	H	L	L	L	486.244	1.553
2	2	H	L	L	R	502.185	9.637
2	2	H	L	R	L	488.914	5.145
2	2	H	L	R	R	505.775	1.502
2	2	H	R	L	L	476.61	2.432
2	2	H	R	L	R	521.335	8.385
2	2	H	R	R	L	486.267	4.004
2	2	H	R	R	R	508.615	4.633
2	2	F	L	L	L	545.981	2.929
2	2	F	L	L	R	566.788	7.633
2	2	F	L	R	L	557.791	2.153
2	2	F	L	R	R	560.678	3.841
2	2	F	R	L	L	554.983	3.53
2	2	F	R	L	R	556.492	4.594
2	2	F	R	R	L	570.395	3.538
2	2	F	R	R	R	552.382	4.825

Table 8.40 - Overall experimental means for Experiment 6.1

mr	soa (ms)	ori (xy)	ori (xz)	res	mean (ms)	mean (%)
1	0	L	L	L	506.135	2
1	0	L	L	R	515.678	5.6
1	0	L	R	L	508.811	3.2
1	0	L	R	R	505.585	4.4
1	0	R	L	L	508.743	4
1	0	R	L	R	517.338	6.4
1	0	R	R	L	527.198	2.4
1	0	R	R	R	505.995	4.8
1	400	L	L	L	472.626	3.2
1	400	L	L	R	490.516	7.2
1	400	L	R	L	477.443	2.4
1	400	L	R	R	482.437	5.2
1	400	R	L	L	480.735	3.6
1	400	R	L	R	486.384	9.2
1	400	R	R	L	478.668	3.6
1	400	R	R	R	471.694	4.4
1	800	L	L	L	454	1.2
1	800	L	L	R	474.94	8.8
1	800	L	R	L	467.637	4.4
1	800	L	R	R	471.588	4
1	800	R	L	L	473.008	5.6
1	800	R	L	R	472.847	2.4
1	800	R	R	L	472.45	2.4
1	800	R	R	R	467.752	3.6
2	0	L	L	L	520.11	3.6
2	0	L	L	R	537.131	4
2	0	L	R	L	536.051	5.2
2	0	L	R	R	534.404	2.4
2	0	R	L	L	533.098	2
2	0	R	L	R	542.472	5.2
2	0	R	R	L	526.404	3.2
2	0	R	R	R	543.865	4.8
2	400	L	L	L	472.298	2.8
2	400	L	L	R	477.895	2.8
2	400	L	R	L	481.657	4
2	400	L	R	R	463.697	4
2	400	R	L	L	472.52	3.6
2	400	R	L	R	487.325	5.6
2	400	R	R	L	477.782	6.8
2	400	R	R	R	465.519	1.2
2	800	L	L	L	463.99	3.2
2	800	L	L	R	482.032	5.6
2	800	L	R	L	472.491	4.8
2	800	L	R	R	475.693	3.6
2	800	R	L	L	476.124	3.2
2	800	R	L	R	477.013	2.8
2	800	R	R	L	486.253	3.6
2	800	R	R	R	464.475	2.8

Table 8.41 - Overall experimental means for Experiment 6.2

mr	ori (xy)	ori (xz)	res	mean (ms)	mean (%)
1	L	L	L	585.488	6
1	L	L	R	606.749	6
1	L	R	L	567.886	4.333
1	L	R	R	606.258	4.667
1	R	L	L	582.582	6.667
1	R	L	R	602.519	8.333
1	R	R	L	578.912	7.333
1	R	R	R	611.713	9.667
2	L	L	L	582.158	1.667
2	L	L	R	614.128	4
2	L	R	L	585.859	3
2	L	R	R	600.945	5
2	R	L	L	581.877	2
2	R	L	R	607.309	4.667
2	R	R	L	585.334	2
2	R	R	R	617.922	5.667

Table 8.42 - Overall experimental means for Experiment 6.3

mr	dist	ori (xy)	ori (xz)	res	mean (ms)	mean (%)
1	F	L	L	L	524.092	7.333
1	F	L	L	R	463.838	2.667
1	F	L	R	L	463.459	2
1	F	L	R	R	498.197	5.667
1	F	R	L	L	485.091	5.667
1	F	R	L	R	498.729	5.667
1	F	R	R	L	524.809	5
1	F	R	R	R	468.164	3.333
1	N	L	L	L	496.395	1.333
1	N	L	L	R	524.181	7.333
1	N	L	R	L	552.389	10.333
1	N	L	R	R	496.735	4
1	N	R	L	L	544.575	4.333
1	N	R	L	R	483.913	4.667
1	N	R	R	L	514.021	4.333
1	N	R	R	R	514.857	5.667
2	F	L	L	L	526.505	5.333
2	F	L	L	R	538.599	2.333
2	F	L	R	L	562.236	8
2	F	L	R	R	503.216	4.333
2	F	R	L	L	551.351	6
2	F	R	L	R	486.79	1.333
2	F	R	R	L	525.424	2
2	F	R	R	R	552.525	7
2	N	L	L	L	558.947	9
2	N	L	L	R	524.966	5
2	N	L	R	L	552.016	4.667
2	N	L	R	R	547.783	3.333
2	N	R	L	L	550.62	4
2	N	R	L	R	583.887	5
2	N	R	R	L	575.329	6.667
2	N	R	R	R	528.983	3.333

8.5 Appendix 5 (Experiment 5.3 condition instances)

Table 8.43 Experiment 5.3- Descriptive statistics for condition instances (n.b. had design been fully counterbalanced all condition instances: mean = 40, sd = 0, min = 40, max = 40).

Response Effector	X-Y Cylinder Orientation	Y-Z Cylinder Orientation	X-Z Cylinder Orientation	Spatial Response	mean (n)	sd	min (n)	max (n)
Feet	Leftwards	Downward	Leftwards	Left	40.10	1.74	37	43
Feet	Leftwards	Downward	Leftwards	Right	41.05	1.67	39	44
Feet	Leftwards	Upward	Rightwards	Left	39.60	2.39	35	45
Feet	Leftwards	Upward	Rightwards	Right	39.85	2.25	36	44
Feet	Rightwards	Downward	Leftwards	Left	40.10	1.92	36	43
Feet	Rightwards	Downward	Leftwards	Right	40.55	1.96	37	44
Feet	Rightwards	Upward	Rightwards	Left	39.35	2.52	35	45
Feet	Rightwards	Upward	Rightwards	Right	39.40	1.43	37	43
Hands	Leftwards	Downward	Leftwards	Left	39.90	1.74	37	43
Hands	Leftwards	Downward	Leftwards	Right	38.95	1.67	36	41
Hands	Leftwards	Upward	Rightwards	Left	40.40	2.39	35	45
Hands	Leftwards	Upward	Rightwards	Right	40.15	2.25	36	44
Hands	Rightwards	Downward	Leftwards	Left	39.90	1.92	37	44
Hands	Rightwards	Downward	Leftwards	Right	39.45	1.96	36	43
Hands	Rightwards	Upward	Rightwards	Left	40.65	2.52	35	45
Hands	Rightwards	Upward	Rightwards	Right	40.60	1.43	37	43

8.6 Appendix 6 (Non-reported experimental series)

The following briefly reports a series of experiments that tested the influence of the functional end of a visual object (e.g. its handle), and how this might interact with the object's orientation. In the first experiment (see Figure 8.43 for example stimuli), the horizontal orientation of a series of kitchen knives and garage files was manipulated (leftwards, rightwards, neutral). The orientation and handle position of the objects were task irrelevant, since participants made left-right responses that classified the identity of the object (e.g. left/knife; right/file). The data revealed an unacceptably high frequency of mistakes and unusually high standard errors (suggesting the distinction between a knife and a file was not an easy one to make). Overall the data was messy with no clearly interpretable patterns.

Figure 8.43 Oriented knives and files, with handle position varied

In the second experiment, an attempt was made to make the task easier by using only one object (a graphically rendered table-tennis bat). The orientation of the bat followed from the cylinder experiments (four global orientations), but the handle position varied for each (see Figure 8.44 for example stimuli).

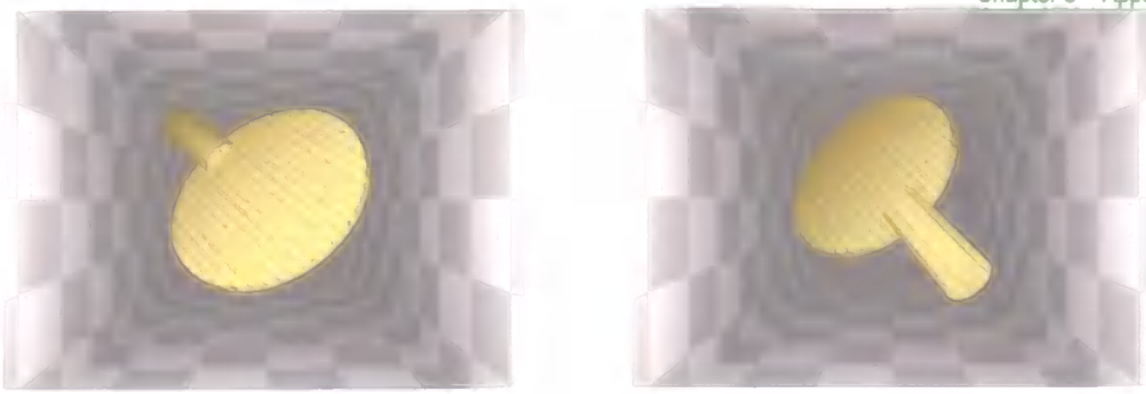


Figure 8.44 Oriented table-tennis bat, with handle position varied

Participants were told that the object was a table-tennis bat, but again, orientation and handle position were task irrelevant, since left-right responses categorised the surface pattern (e.g. left/wobbly; right/straight). The data supported an attention-directing account, for all advantages in performance (RTs and mistakes) occurred for responses that were the same side as the end of the object that was nearest to the viewer. It appeared that wherever the clearest and largest area of the object was; this was where participants had attended to in order to retrieve the clearest source of information about the surface pattern.

A third experiment used a dual-function object (in a similar manner to the experiment proposed in Chapter 7, where an object could be an ink stamp or a bottle stop). For one group of participants the object was a pestle (and before trials began, participants had to use a scale model of the object as a pestle, grinding matter in a mortar bowl). For another group of participants the object was the handle component of a pump (and before trials began, participants had to use the same scale model of the object that was now attached to a pump device, in order to blow up a balloon). Thus for the pestle group the functional end of the object was perceived to be the cylinder component, whereas for the pump group the functional end of the object was perceived to be the ball component (see Figure 8.45 for example stimuli). Again, the object's orientation and functional-end position were task irrelevant, since left-right responses categorised the surface pattern (e.g. left/wobbly; right/straight). This experiment was run in parallel to the table-tennis bat experiment, and unwittingly was subject to the same design flaw. Thus the data again suggested that wherever the clearest and largest area of the object was; this was where participants had attended to in order to retrieve the clearest source of information about the surface pattern.

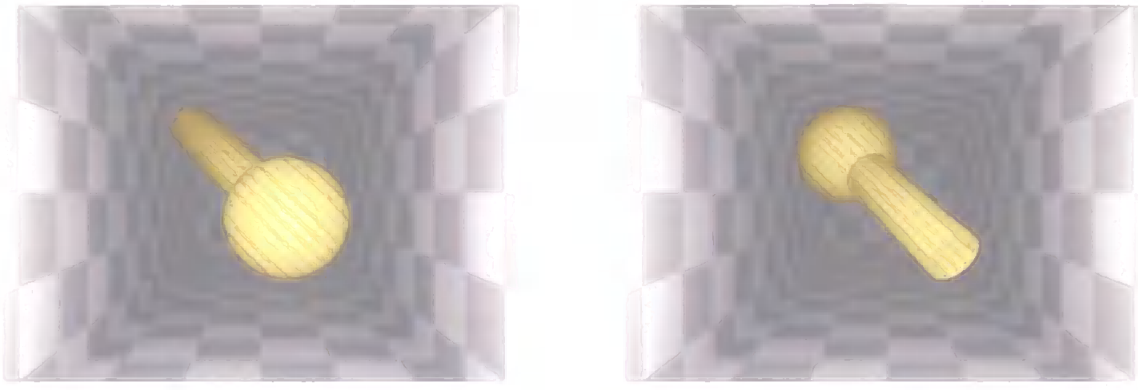


Figure 8.45 Oriented pump-or-pestle, with functional end position varied

It will therefore be noted that the 'ink stamp/bottle stop' experiment proposed in Chapter 7 avoids any visually salient areas from which a response can be based, by making the task to do with the object's functional identity within the context of which direction it is said to be moving (e.g. 'towards me', 'away from me').

9. References

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