Micro-affordances during lexical processing: considerations on the nature of object-knowledge representations

by

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Abstract

Micro-affordance effects have been reported for several different components of the reach-to-grasp action during both on-line and off-line visual processing. The presence of such effects represents a strong demonstration of the close relationship between perception, action, and cognition. In this thesis 7 experiments are described, which investigate different aspects of that relationship, with particular attention on the nature of object representations. In 5 behavioural experiments as well as in 1 Transcranial Magnetic Stimulation (TMS) experiment a stimulus-response compatibility paradigm is employed to examine the presence of micro-affordance effects arising during language processing of object names. The power and precision component of the reach-to-grasp action is investigated in relation to the compatibility of an object for grasping with either a power or a precision grasp.

Overall, the results of the experiments discussed in the present thesis suggest that: a) object representations activated during language processing of object names are able to potentiate actions arising from the component of the reach-to-grasp action under investigation; b) such representations might be more semantic or 'propositional' than depictive in nature, therefore more related to stored semantic knowledge of the object and its associated actions than to its detailed visual properties; c) this semantic information about objects seems to be automatically translated into specific motor activity, even in the absence of any intention to act; d) finally, such semantic, non-visual motor potentiation seems to be rapid and relatively short lived.

Riassunto

Gli effetti di compatibilità micro-affordance sono stati riportati per diverse componenti dell'azione di raggiungimento e prensione, sia durante l'osservazione on-line di oggetti che durante la loro elaborazione visiva off-line. La presenza di simili effetti rappresenta una forte dimostrazione della stretta relazione che intercorre tra percezione, azione e cognizione. Nella presente tesi, sono stati inseriti sette esperimenti miranti ad indagare diversi aspetti di questa relazione, con particolare attenzione alla natura delle rappresentazioni degli oggetti. In cinque esperimenti comportamentali, così come in un esperimento di Stimolazione Magnetica Transcranica (TMS), un paradigma di compatibilità stimolo-risposta è stato impiegato per esaminare la presenza di effetti di compatibilità micro-affordance emergenti durante l'elaborazione linguistica di nomi di oggetti afferrabili. Le componenti di afferrabilità 'power' (presa a mano intera) e di precisione (tra indice e pollice) sono state indagate in relazione alla compatibilità di un oggetto ad essere afferrato o con una presa power o con una di precisione.

Complessivamente, i risultati degli esperimenti descritti in questa tesi suggeriscono che: a) le rappresentazioni degli oggetti attivate durante l'elaborazione linguistica dei loro nomi sono in grado di potenziare le azioni evocate dalle componenti dell'azione di prensione indagate; b) tali rappresentazioni potrebbero essere semantiche o 'proposizionali' piuttosto che 'figurative' o visive, pertanto più legate alle conoscenze semantiche immagazzinate degli oggetti e delle azioni ad essi associate che alle loro specifiche proprietà visive; c) l' informazione semantica relativa agli oggetti sembra essere automaticamente tradotta in attività motoria specifica, anche in assenza di una qualsiasi intenzione ad agire; d) infine, questo potenziamento motorio, semantico, non visivo sembra presentarsi molto rapidamente ed essere di durata relativamente breve.

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Author's Declaration

I have read and understood the University of Edinburgh guidelines on plagiarism and declare that this thesis is all my own work, except where I indicate otherwise by proper use of quotes and references.

At no time during the registration for the degree of Doctor of Philosophy has the work been submitted for any other degree or professional qualification, neither has it been published in whole or in part.

Date…………………….   Signed………………….

Chapter One

1.1 Introduction

Imagine that a friend of yours asks you to pass the glass situated on the desk you are sitting at. As soon as you hear the word ‘glass’, you have to visualize it, reach for it, grab it, pass it to your friend, and release the grip. Though this seems a simple everyday routine task, it entails the engagement of different linguistic, perceptual, motor systems and circuits of the brain that control the performance of the sensors and effectors involved. The studies included in this thesis were undertaken with the general aim to provide new insights into the nature of the complex relationship between language processing and perception and action systems. Seven experiments are described, which investigate different aspects of that relationship, with particular attention on the nature of object representations.

A growing body of evidence suggests that words are closely related to their referents and, as claimed by the embodied or grounded theories of cognition (e.g., Barsalou, 2008), deep-seated in perception, action and sensorimotor processes. It has been suggested that during language processing of words, perceptual and motor information regarding words’ referents can be evoked. Some indication of this link comes from several studies employing different measures and research techniques, such as reaction time measures (Borghi, Glenberg, Kaschak, 2004; Borreggine, Kaschak, 2006; Boulenger, Roy, Paulignan, Deprez, Jeannerod, Nazir, 2006; Buccino, Riggio, Melli, Binkofski, Gallese, Rizzolatti, 2005; Scorolli, Borghi, 2007), kinematic measures (Gentilucci, Gangitano, 1998; Glover, Dixon, 2002; Glover, Rosenbaum, Graham, Dixon, 2004; Nazir, Boulenger, Roy, Silber, Jeannerod, Paulignan, 2008), eye tracking technique (Huettig, Altmann, 2005; Spivey, Geng, 2001; Tanenhaus, Spivey-Knowlton, Eberhard, Sedivy, 1995), brain imaging techniques (Grafton, Fadiga, Arbib, Rizzolatti, 1997; Kellenbach, Brett, Patterson, 2003; Pulvermüller, 2003; Kemmerer, Castillo, Talavage, Patterson, Wiley, 2008), and Transcranial

Magnetic Stimulation (TMS) technique (see, for example, Buccino, Riggio, Melli, Binkofski, Gallese, and Rizzolatti, 2005; Cattaneo, Delvin, Salvini, Vecchi, and Silvanto, 2010; Gough, Riggio, Chersi, Sato, Fogassi, Buccino, 2012).

Of most relevance to this thesis, however, it seems that, similarly to what happens with visual objects (real or pictures), object names can evoke ‘affordances’. According to James Gibson’s (1979) ecological approach to perception, the world is perceived not only in terms of objects’ shapes and their spatial properties but also in terms of object possibilities for action. That is people not only perceive the physical properties of an object or tool, but also what they can do with it. Within this approach, affordances are described as the functional characteristics of an object and the possible actions it could afford based on the motor capabilities of the perceiver. A given object may afford a whole range of behavioural possibilities (e.g., it may be thrown, grasped, pressed, kicked, etc.), only if the physiology of the perceiver or agent (i.e., his/her body structure and bodily characteristics) is consistent with the afforded action. For example, a door handle may afford opening to adult humans, but not to a baby or to a dog.

Whilst Gibson coined the term affordance to indicate the more general possibilities for actions, Ellis and Tucker (2000) introduced the notion of ‘micro-affordance’ to characterize the objectual features typically suggesting or even demanding *specific* object-related motor acts. A graspable object, for example, affords not only grasping in general, but specific components of a grasping action, a grasp appropriate to its characteristics (e.g., a particular shape of the hand or a particular orientation of the wrist). Though the similarity in terminology, these authors’ perspective substantially differentiates from the original concept of affordances. According to Gibson, the mere sight of an object can automatically elicit its affordances but, importantly, it is the object itself that affords the action and the viewer can directly perceive this affordance. In purporting that vision (or perception) is a ‘direct’ process, Gibson rejected the idea of internal representations and considered affordances as a property of the object. Micro-affordances, by contrast, are seen as a property of the perceiver's nervous system, are conceived of as cell assemblies of the brain that represent objects, and derive from previous interactions with objects. These representations are thought to contain encodings of the actions that can be carried out on objects that, once activated, can automatically potentiate specific motor plans associated with those objects.

The concepts of affordances or micro-affordances have often been put forward to explain the existence of the so called stimulus-response (S-R) compatibility effects (see for example Michaels, 1988;1989; Michaels and Schilder, 1991; Tipper et al., 2007). S-R compatibility effects are typically observed when some combination of a stimulus dimension and an organism's response results in faster reaction times (or more accurate responses) than an alternative combination. For instance, pressing a left key in response to a stimulus presented on the left results in faster or more correct responses than pressing a left key in response to a stimulus presented on the right. In this case, the stimulus dimension responsible for the effect (i.e., its spatial location) is task relevant. Nevertheless, these effects can be observed even when the stimulus location is task-irrelevant as in the case of the well documented S-R compatibility effect named 'Simon Effect' (Simon, 1969). It has been shown that right and left hand responses to stimuli in the compatible visual hemifield are faster than left and right hand responses in the incompatible visual hemifield, even when this stimulus dimension is irrelevant to the task at hand. For instance, when participants are instructed to respond differentially to two different coloured stimuli, one placed on the right side of the visual field and one on the left, response latencies are faster if the stimulus shares the same spatial dimension (right/left, irrelevant to their task) with the hand making the response (right or left). These spatial compatibility effects do not depend on the correspondence between side of the visual field and hand making the response, as demonstrated by Anzola et al. (1977) who found that the same effects were observed even when participants performed a similar task with crossed hands (right hand in the left side of the body and left hand in the right side). So, it is the correspondence between the stimulus and the key that matters (see also Riggio, Gawryszewski, and Umiltà, 1986).

Similar S-R compatibility effects produced by task irrelevant stimulus features have been observed in the affordances or micro-affordances studies. The traditional paradigm employed in these studies was such that participants were presented with either pictures of objects or the objects themselves and asked to categorise them by making a manual response. For example, in Tucker and Ellis's (1998) seminal study participants were shown pictures of everyday graspable common objects (e.g., saucepans, hammers, teapots, etc.). The objects were presented either in their correct orientation or upside down, and participants had to categorise them according to this distinction by pressing either a key with their right hand or another key with their left hand. Half the participants were instructed to press the left key for objects in their correct orientation and the right key for objects upside down, whilst the other half received the reverse response mapping. The analysis of the reaction times revealed that response times to the categorisation task were significantly faster on trials where the observed object was optimally positioned for a grasping action by the hand making the response, that is when the hand was ipsilateral to the position of the object handle. In addition, the analysis of the error data revealed that responses were more accurate when there was the same compatibility between object orientation and responding hand.

The compatibility effects shown in these experiments have been interpreted as demonstrating that visual or 'seen' objects can facilitate components of a grasping action in the viewer. Importantly, this motor facilitation is produced by a stimulus property not relevant to the task at hand, as described in the above study where the positioning of objects in terms of their right-left orientation was irrelevant to the categorisation task.

Most of the traditional information processing explanations of S-R compatibility effects are based on the concept of abstract codes, which are formed automatically during visual processing. According to this perspective, such codes can either facilitate or interfere with responses depending on the congruence between stimulus and response. Congruent or incongruent effects are thought to be caused when a ‘dimensional overlap’ occurs between stimulus and response (e.g., Kornblum et al., 1990; Kornblum, 1994). For instance, when stimuli are presented in the right visual hemifield, right hand responses are faster than when stimuli are presented in the left visual hemifield because both stimulus and response share the ‘right spatial dimension’.

As mentioned above, an alternative explanation of S-R compatibility effects can be provided by the Gibsonian perspective. Within this view, the results obtained in S-R compatibility experiments (faster reaction times and more correct responses) reflect the degree to which a perceiver’s action is afforded by the environment (i.e., the stimulus). For example, the spatial Simon Effect can be seen as a consequence of affordances that arise from the position of an object (e.g., orienting toward, pointing at, grasping, etc.). All these affordances are thought to facilitate responses in the direction of the stimulus, and this leads to faster response times or more correct responses as reported in Simon Effect experiments. Like in all ecological theories, and as mentioned before, this account rejects the notion of internal representations because affordances are considered as properties of the environment directly perceived.

Differently from both the previous explanations, within the micro-affordances account S-R compatibility effects have been interpreted as providing evidence that object representations contain encodings of the possible actions that can be performed on objects. Even thought still situated within an information processing framework, this alternative account, however, interprets the compatibility effects as the result of the direct association between the response code and the code for the relevant stimulus property without the need for a further level of abstract coding. It is argued that these associations have developed either throughout the individual life-time (i.e., through ontogenesis) or over an evolutionary time-scale (i.e., phylogeny), as part of the process of adapting to the environment.

These phenomena have mostly been investigated using real objects or object pictures while being observed on-line. However, supports for the notion that object representations contain such action encodings are not limited to studies concerned with on-line visual processing of objects. Derbyshire, Ellis and Tucker (2006), for example, found that affordance-based compatibility effects can emerge even during off-line visual processing of objects, that is when objects are imagined or remembered. Furthermore, as will be discussed in the next section, similar effects can also be elicited by linguistic information about objects, as in the case of object names and action related nouns.

1.2 Object Concepts, Language, and Action

Successful adaptation to the environment necessarily passes through appropriate interactions with objects that constitute it. The ability of human beings to properly interact with objects depends on their capacity for storing information about objects and categorizing them, thus forming concepts. So, a given concept consists of the information we typically associate with its referent, that is what we know about the object that concept refers to.

According to the traditional perspectives, object concepts are made of abstract, propositional symbols related to their referents in an arbitrary way. For example, our concept of ‘bicycle’ would be formed of a list of properties or statements that are represented in a propositional way (e.g., ‘pedals, saddle, handlebars, wheels’) (Fodor, 1998). In sharp contrast with this view, the embodied and grounded perspective proposes that concepts are neither abstract nor arbitrary but deeply grounded in sensorimotor activity. Namely, they consist of the re-enactment of the experiences we had with their referents (Barsalou, 1999; Harnad, 1990; Thelen and Smith, 1994). Within this view, the activation of object concepts leads to a re-experiencing (i.e., a simulation) of the interaction with those objects, and such simulations in turn support the actual interaction with them. Therefore, concepts can be conceived of as blueprints that tell us how to act, or as patterns of potential actions (Glenberg, 1997).

This mechanism also occurs in the case of concept-nouns, that is when concepts are expressed through words. Indeed, a massive corpus of evidence suggests that language is grounded in perception and action. For example, it has been shown that linguistic information about graspable objects (e.g., object names and action related nouns) can have consequences for affordance processing, both by acting as top-down cues attracting attention to the named objects and by potentiating associated affordance components via the link between lexical and motor representational components. Klatzky and colleagues (1989) showed that preparing for a grasp may influence understanding of the words associated with similarly grasped objects, and hearing grasp-related words may facilitate visual processing of graspable objects. In particular, they verbally instructed participants to adopt a hand shape (e.g., pinch or clench). Once participants adopted the hand shape, they had to decide whether a particular action description (e.g., eat a carrot) was sensible or not. Adopting hand shapes that were congruent with the object referred to in the action description facilitated these sensibility decisions. This finding was confirmed and extended in more recent studies. Tucker and Ellis (2004) demonstrated that showing a graspable object's name produced a congruency effect on manual responses similar to the one commonly observed in visual object categorization studies (see also Borghi, Bonfiglioli, Ricciardelli, Rubichi and Nicoletti, 2007). Similar effects were reported in Bub, Masson, and Cree (2008) for both functional (grasping) and volumetric (lifting) actions (see also Lindemann et al., 2006). Furthermore, in some studies by Masson, Bub, and Newton-Taylor (2008), Masson, Bub, and Warren (2008), and Bub and Masson (2010) it was found that the linguistic elicitation of affordances is not limited to single-word processing. In their studies, functional gestures were produced faster after participants had read or listened to sentences referring to objects that afford similar grasps.

Affordance effects can be triggered not only by nouns but by verbs as well. A series of recent reports using a variant of the sentence-picture verification task showed that functional (grasp) and manipulation (drink) verbs related to graspable objects give rise to affordance effects in a fashion similar to nouns (Ambrosini et al., 2012; Borghi and Riggio, 2009; Constantini et al., 2011).

Put together, the studies reviewed thus far demonstrate that hearing or reading a graspable object name or a verb related to manipulating the object leads to sensorimotor simulations of the associated grasp affordances.

The idea that during language processing the same perception and action systems are recruited as when interacting with objects is in line with the 'neural exploitation hypothesis' (Gallese and Lakoff, 2005; Gallese, 2008; Glenberg, 2008), a model of neural re-use (Anderson, 2010). It has been proposed that, since evolution is conservative, language relies on previously developed systems, such as the action system. The similarities between language and action have been underlined in a series of studies showing how language reflects some characteristics of action organization (for a review see Borghi, 2012).

In literature, the notion of 'simulation' (or 'emulation', as proposed by Grush, 2004) has been used with different meanings. Here the term simulation includes two crucial aspects. First, as already mentioned, it refers to the embodied process of an unconscious and not deliberate re-enactment of past sensorimotor experiences (Barsalou, 1999). Second, simulation has a predictive character (Grush, 2004; Pezzulo and Castelfranchi, 2009) as it prepares for action (Gallese, 2009). For example, when we read the sentence 'pick up the glass' the same perceptual and motor systems are recruited (i.e., re-enactment) as when actually performing the action. At the same time, however, reading that sentence leads us to prepare the appropriate interaction behaviour, in this case a power grip (i.e., the appropriate grip suitable to hold an object by using all hand fingers) rather than a precision grip (i.e., the typical grip used to pick up small objects by using only index finger and thumb).

A considerable number of studies on embodied cognition have highlighted the similarity between the simulation triggered during observation of actions or objects and the simulation evoked by language. Nevertheless, there are important differences. The recent distinction between ‘stable’ and ‘variable’ affordances proposed by Borghi and Riggio (2009) might help distinguish what happens when we observe a visual object, and what happens instead when we listen to or read object words.

Stable affordances would emerge primarily from intrinsic properties of the affording objects like general graspability, size, shape, or weight. They are hypothesized to be stored permanently as components of the object off-line representation, elicited automatically and independently from specific visual contexts. Stable affordances do not change across contexts as they pertain to permanent characteristics of an object, thus they are often referred to as ‘stored’ or ‘core’ affordances. Variable affordances, on the contrary, are related to contingent and context-specific object properties. They depend on more temporary aspects of an object (e.g., its orientation) that vary according to the way in which the object is shown, thus they are also termed ‘temporary’ or ‘situated’ affordances. In order to better understand the distinction proposed, one could think of a saucepan. Its stable affordance will result from the fact it has a handle that has to be grasped (e.g., by wrapping the whole hand around its handle) in order to use it. The type of grip used to interact with the saucepan is expected to be encoded in its stored, off-line representation, but information concerning the current orientation of its handle has to be processed online as it is dependent of how the saucepan is spatially presented at any given moment. However, it is worth noting that there are some kinds of orientation that are associated with the typical interaction with an object (Palmer, Rosch, Case, 1981; Riddoch, Humphreys, Hickman, Clift, Daly, Colin, 2006). These object typical orientations are referred to as ‘canonical’ affordances and represent a special case of variable affordances. For example, even though people can interact with saucepans in different orientations (e.g., when washing or moving them), when we use a saucepan it more frequently has a typical orientation, namely it is positioned upright on the stove as we use it for cooking. Due to the higher frequency of this orientation when people use saucepans, it would be useful to store in memory information about their canonical orientation, whilst, on the contrary, it would be highly uneconomical to permanently store all possible orientations saucepans can assume (but see also Biederman, 1987 for a model of object perception and recognition).

As mentioned above, the distinction between different kinds of affordances helps differentiate the simulation involved during the observation of a visual object from that activated by linguistic information about it.

One hypothesis could be that words that refer to objects are not grounded in sensorimotor experiences, thus they are not linked to their referents in terms of their perceptual and motor characteristics. In this case, words would only be processed and understood in terms of other words associated to them (Landauer and Dumais, 1997). Another possibility could be that during language processing of an object word, the perception and action systems activated are the same as when observing or actually interacting with the corresponding object. This is consistent with the ‘indexical hypothesis’ (Glenberg and Robertson, 2000) according to which words (or sentences) are deeply linked to objects in the world, or to their analogical representations as pictures or perceptual symbols (Barsalou, 1999). Within this view, words that refer to objects would evoke perceptual and motor information relative to them. To test this hypothesis, in a study by Borghi (2004) participants were presented with a series of sentences (e.g., ‘the body extracts the book’) followed by a word; participants’ task consisted of deciding whether or not the word referred to a part of the object mentioned in the sentence. These parts could afford an action or not. For example, the word ‘cover’ is a better affordance for the action of extracting a book than the word ‘page’. Results showed that words referring to parts from which it was easy to derive affordances were processed more quickly, despite no difference in semantic association between the affording and not affording part words and the previous sentence was found. These results seem to support the indexical hypothesis as they suggest that the way people understand words or sentences is not explained by associative relations between words, but it is constrained by the affordances elicited by the objects words refer to.

This hypotheses was further confirmed and extended in a study by Borghi and Riggio (2009), who tried to investigate what kind of affordances are activated during language processing. Having employed a recognition task (Stanfield and Zwann, 2001), in a typical trial participants were first presented with a sentence that could include either an observation verb or an action verb in imperative form (e.g., look at vs. grasp the brush). After 400 ms the sentence was replaced by an object picture, and participants had to decide whether or not the object shown had been mentioned in the previous sentence by pressing a different key. The objects could be compatible with either a power or a precision grip (e.g., brush vs. pencil), and could have their canonical orientation (i.e., have the affording part in the lower part of the screen vs. on the higher part of the screen) or not. Results showed that action verbs were processed faster than observation verbs, even though the verb frequency was the same. This suggests that the facilitation observed was due to the fact that action verbs induced the production of an action.

In addition, when the objects were presented in their canonical orientation, RTs were faster in the condition where the canonical orientation and the current orientation of the object matched compared to the condition in which there was a mismatch between orientations.

The most interesting results, however, concern false trials in which the object mentioned in the sentence was different from that shown in the picture. It was found that in the condition where there was a congruency between the grip that would be required for interacting with the object in the sentence and the grip that would be required for interacting with the object in the picture (e.g., when the word ‘brush’ was followed by the picture of another object compatible with a power grip, such as a hammer), RTs were slower with action verbs than with observation ones, probably due to an inhibition of the motor system. This result suggests that when we read an action sentence we prepare ourselves to act with a given object, and that the object name activates the way we should grasp it. In other words, we represent an object in terms of its size, and of the grip it evokes. The inhibitory effect observed is compatible with the Theory of Event Coding (TEC) (Hommel et al., 2001), according to which if an event file is activated from two different sources (in this case by both the linguistic task and the motor one), an inhibitory process takes place.

Taken together, these results allow us to characterize the simulation formed during language processing, and to understand what kind of affordances are evoked. They suggest that during language processing we form a rather detailed simulation. Similarly to the simulation triggered during object observation, it re-activates previous perceptual and motor experiences, which prepare us to act. Thus, the way we understand sentences involving objects or words referring to objects is linked to object affordances, rather than to associative relationships between words. However, the simulation formed during language processing differs from the simulation built while observing objects in that it activates only stable and canonical affordances, i.e. it anticipates the object properties which have been frequently experienced and have a higher probability to be encountered. Differently from what happens during object observation, it seems that the more variable properties of objects are not involved in language processing.

In the next section, it will be discussed that this distinction between stable and variable affordances is reflected, at a neural level, in the distinction between two different neural pathways, namely the ventral and dorsal neural pathways.

1.3 Two Routes to Action

In this section, a body of evidence will be reported in support of the claim established over the years that humans (and other animals) possess two functionally distinct but complementary visual pathways. One of these, the dorsal stream, projects from the primary visual cortex to the posterior parietal cortex, whilst the other, the ventral stream, projects from the primary visual cortex to the inferotemporal cortex (Milner and Goodale, 1995).

For simplicity in exposition, the section is divided into three sub-sections in which neurophysiological, neuropsychological, and behavioral evidence will be provided for the existence of such distinct processing streams that are thought to mediate two different routes to action: a direct visual route, mediated by the dorsal stream, and another route which implies access to semantics and is mediated by the ventral stream (Rumiati and Humphreys, 1998).

1.3.1 Neurophysiological Evidence

As suggested by preliminary investigations into the role of these two neural pathways, the ventral stream was believed to be mainly responsible for object recognition, whereas the dorsal stream was thought to be primarily responsible for object location in space. Indeed, in studies of non-human primates it was found that lesions to the ventral system led to impairments in object recognition, whilst disturbances in the localization of objects were found following lesions to the dorsal system (Ungerleider and Mishkin, 1982). Due to such functional differences, the ventral and dorsal neural pathways were labeled as the ‘what’ and ‘where’ pathways respectively.

The functional division between the ventral and dorsal systems was initially believed to reflect a similar division observed earlier in the visual pathway concerning the functioning of two types of cells, namely the ‘magnocellular’ and ‘parvocelluar’ cells, localized in the retina, LGN and Primary visual cortex (Reid, 1999). It was found that magnocellular cells possess spatio-temporal properties underlying the perception of motion and detection of sudden stimulus onsets. On the contrary, parvocellular cells display properties suitable for the detection of colour, pattern and texture variations, which are important for object recognition. Even though the ventral and dorsal systems receive inputs from both kinds of cells, within each of these two neural circuits there are cells that display unique properties absent in the other region. For instance, there is a class of neurones within the posterior parietal cortex that fire during both sensory-related and movement-related activity. Within this region, different subsets of neurones are active during eye-hand coordination, visually guided reaching movements and saccadic eye movements (Andersen, 1987), whereas others respond to the visual qualities of objects that determine the posture of hand and fingers during a grasping action (Taira, Mine, Georgopoulos, Murata, Sakata, 1990). Likewise, neuronal cells within the inferotemporal cortex have been found to respond to form, pattern and colour. In addition, in this region, and in neighbouring temporal lobe areas, there are cells that are sensible selectively to precise objects (Miyashita, Date and Okuno, 1993), faces (Bayliss, Rolls, and Leonard, 1985; Desimone, 1991), and hands (Gross, Rocha-Miranda, and Bender, 1972).

Such functions and related brain areas identified in the single cell studies of non-primates are consistent to those emerged in neuroimaging studies of non-brain damaged humans. For example, Matsumura et al. (1996) have found that the posterior parietal cortex is preferentially activated when participants are engaged in visually guided actions (i.e., during reaching movements, grasping movements, and eye saccades). Similarly, brain imaging studies of the occipitotemporal region have shown that it is selectively activated during processing of colour, texture, and differences in object form (Puce, Allison, Asagari, Gore, and McCarthy, 1996; Price, Moore, Humphreys, Frackowiak, and Friston, 1996; Malach, Reppas, Bension, Kwong, Jiang, Kennedy Ledden, Brady, Rosen, and Tootell, 1995; Kanwisher, Chun, McDermott, and Ledden, 1996).

The evidence reported so far, together with the neuropsychological evidence to be presented in the next sub-section, has conduced to a revision of the ‘what’ and ‘where’ descriptions assigned to the ventral and dorsal pathways. In fact, it is now accepted that the pathways are more appropriately described as the ‘what’ and ‘how’ pathways.

1.3.2 Neuropsychological Evidence

As just mentioned above, instead of the ‘what’ and ‘where’ pathways, it would be more apt to describe the ventral and dorsal pathways as the ‘what’ and ‘how’ pathways. Having observed a patient, D.F., suffering from visual object agnosia after carbon monoxide-induced anoxia, Goodale and colleagues (Goodale, Milner, Jakobson, and Carey, 1991; Goodale and Milner, 1992; Goodale, 1993; Milner and Goodale, 1995) introduced the notion of ‘what’ and ‘how’ pathways. The patient’s brain scans displayed a quite diffuse damage but it was mainly observed in the ventrolateral regions of her occipital lobe, whilst the primary visual cortex was relatively spared. The clinical examination of D.F.’s difficulties revealed that she was unable to recognize objects from their visual contours and to describe or distinguish different objects during a discrimination test. Despite this, she conserved her ability to recognize objects from their colour or other surface features (Humphreys, Goodale, Jakobson, and Servos, 1994). In addition, she was unable to adjust her fingers to fit the size of a visually presented object but, if asked to actually grasp the same object, she could accurately perform the correct grasping movement. The same kind of dissociation was apparent while trying to perform orientation tasks. When asked to align her hand with the orientation of a slot positioned at a series of different orientations, or even to verbally describe the different orientations, she failed to perform the task but, if asked to actually post a card using the differently oriented slots, her performance was almost comparable to that of typical individuals.

Such a dissociation between vision for action and vision for recognition has also been found in other patients. For example, Riddoch and Humphreys (1987) reported the case of J.B., a patient with extensive brain damage of the left hemisphere who suffered from optic aphasia after a road traffic accident. Clinical observations revealed that J.B. was poor at naming objects and accessing semantic information associated with those objects, but could still make appropriate gestures towards the same objects when viewing them.

It is worth noting that the visual system requires knowledge of objects' features in order to either recognize objects or make appropriate actions or gestures towards them. In the case of D.F. and J.B., information about these features was available to the visual system, considered their spared abilities to make appropriate actions or gestures towards objects, yet they could not use that same information to both describe and recognize those objects. Considering the kind of deficits displayed and that spread brain damage to the ventral route was found in both patients, the case studies described so far represent strong neuropsychological evidence for the existence of two distinct visual systems, one primarily responsible for object recognition and the other primarily responsible for visuomotor abilities.

Additional support for distinct neural pathways comes from neurologic patients who manifest the opposite dissociation between vision for action and vision for recognition. For example, Riddoch, Humphreys, and Price (1989) described a patient, C.D., who suffered from apraxia after a cerebral bleeding caused by hypertension. This condition resulted in a parietal lesion to the left hemisphere which led to the onset of a pattern of deficits opposite to those described so far. C.D. displayed no impairments of object recognition and his naming abilities were normal, but he was unable to make the appropriate gestures towards the same objects. Interestingly, this impairment was restricted to the right hand and was more apparent when he was asked to make gestures to seen objects compared to when he was asked to respond to the names of the same objects.

It has to be said, however, that the pattern of deficits manifested by C.D. are consistent with much earlier descriptions of deficits observed in head wound patients during World War One. It was not uncommon to find patients who were unable to locate objects but absolutely able to recognize them (e.g., Holmes, 1918). For example, in one of these reports there is the description of a patient who could not grasp a pocket-knife even though he could correctly identify it. Indeed, his attempts to grasp the pocket-knife produced only grasping actions in the wrong direction.

At first glance, one could consider the class of deficits displayed by both C.D. and World War One head injured patients as a class of deficits in spatial abilities. A deeper analysis, however, suggests that this could not be the correct interpretation if it is considered that patients, who are unable to perform the appropriate action towards objects, can often describe their relative location in the visual field controlateral to their brain lesions (Jeannerod, 1988). Rather, it seems more apt to interpret such deficits as a consequence of visuomotor impairments, hence once again it would be more appropriate to use the term ‘how pathway’ instead of ‘where pathway’.

1.3.3 Behavioural Evidence

The idea of two distinct processing streams, one for object recognition and one for visuomotor activity, also finds support in a considerable number of behavioural studies with non-brain damaged individuals. In this sub-section, however, only a few studies most relevant to the present thesis will be mentioned.

For example, the results of a study by Rumiati and Humphreys (1998) provide good empirical evidence for the existence of dual, independent routes to action from vision. In one experiment, participants were instructed to either name line drawings of objects or make appropriate gestures towards them under time pressure. During both conditions, participants could make two main types of errors, ‘visual’ or ‘semantic’ errors. The visual errors were considered as those errors in which participants gave “response to another item that was similar in shape to the target but was neither associated with the target nor from the same functional category (e.g., razor → hammer)” (p. 634). The semantic errors were defined as those in which participants gave “response to another item that was associated with the target or from the same functional category but not visually related to the target (e.g., hammer → saw)” (p. 634).

The error analysis showed a significant difference in the number and types of errors depending on the experimental condition, that is to say depending on whether or not participants were naming the objects or making gestures towards them. In particular, in this first experiment, it emerged that participants tended to make more visual errors while gesturing than while naming, whilst more semantic errors were found during naming than during gesturing.

In a second experiment, participants were asked to produce the same kind of responses to a number of line drawings (i.e., appropriate naming or gesturing), but, this time, half of the trials were replaced with object written names. Once again, the error analysis revealed more visual errors during gesturing than during naming, and more semantic errors during naming than during gesturing. Interestingly, during gesturing to words participants tended to commit only semantic errors to words, thus no visual errors were found in this condition.

On one hand, the fact that more semantic errors were found during the naming of object pictures and during the gesturing of object written names was interpreted as evidence for the activation of a route to action mediated by semantic-functional knowledge about objects. On the other hand, the finding that visual errors were made during gesturing only to pictures of objects but not to their written names provides evidence for the existence of a direct route between visual information and action, which does not seem to require the mediation of object semantic knowledge.

Another behavioural experiment that provides evidence consistent with the idea of two separate visual processing streams was carried out by Aglioti, DeSouza and Goodale (1995). In the experiment, a three-dimensional version of the Ebbinghaus Illusion was employed.

Similarly to what happens in the standard illusion, on each trial participants were presented with two 'target' discs, one on the participants' right field of view and one on the left field of view. One of the two discs was surrounded by discs larger than itself, whereas the other was surrounded by discs smaller than itself.

Trials were then randomly alternated so that on some trials the target discs were physically different in size to each other but appeared perceptually identical, whilst on the other trials the target discs were physically the same size but appeared perceptually different. Participants were asked to decide whether the discs were either the same or different size. If they thought the discs were the same size they had to pick-up the target disc on the right, while if they thought the discs were different they had to pick-up it on the left. Consistent with the standard two-dimensional version, the results revealed that participants were sensitive to the illusion.

Most importantly, however, during the task also the aperture of participants' grip (i.e., the amplitude observed between thumb and index finger) was measured. The results of the analysis conducted on these data revealed that the maximum aperture recorded when participants went to pick up a target disc was determined exclusively by the actual size of the target disc, not by its perceived size. These results can be interpreted as showing that vision for action is not sensitive to the size contrast illusion, whereas vision for recognition and visual comparison is. Once again, this interpretation is consistent with a dissociation between vision for action and vision for recognition.

Similar results have also been reported by Haffenden and Goodale (1989) and Westwood, Heath and Roy (2000).

Further behavioural evidence for such a dissociation comes from the already mentioned micro-affordance studies documenting S-R compatibility effects (see, for example, Tucker and Ellis, 1998, 2001; Ellis and Tucker, 2000; Ellis, Tucker, Symes, and Vainio, 2007). As described in the introduction above, these studies demonstrate that simply viewing an object can facilitate actions in the viewer when the stimulus property, which produces the facilitatory effect (i.e., typically faster and/or more correct responses), is compatible with the response type and is task-irrelevant. This facilitation has been observed for different properties of objects, such as their orientation (see, for example, Tucker and Ellis, 1998) or their size/shape (see, for example, Tucker and Ellis, 2000), thus it involves both variable and stable object affordances. To explain these effects, the micro-affordance account proposes that the representations activated during the visual processing of objects contain encodings of the actions that can be carried out on them.

On one hand, the involvement of action in visual processing is consistent with the idea of a 'dissociation' between vision for recognition, which is thought to be under the remit of the ventral stream, and vision for action, which is thought to be under the remit of the dorsal stream. On the other hand, however, the micro-affordance account hypothesizes a mutual dependence of the dorsal and ventral systems, arguing that visual object representation in the brain is the coupling of visual responses with action related responses. In other words, object representations contain encodings for both the visual descriptions of objects and for the actions that can be carried out on them.

Indeed, even though the emphasis in this and the previous sub-sections has been to provide evidence in favour of the existence of separate processing streams, it worths noting that the dorsal and ventral pathways can show complex interconnectivities (Goodale, Jakobson, and Servos, 2000). Consistently with this claim, more recent evidence seems to indicate that the distinction between 'acting' and 'knowing' brain systems might be too rigid and dichotomic (Gallese, Craighero, Fadiga, and Fogassi, 1999; see also Derbyshire, Ellis, and Tucker, 2006). For instance, studies with words that refer to objects contribute to settle the debate between those who claim that the compatibility effects observed between task-irrelevant object features and the motor acts used to perform the task are due solely to on line processing of object visual information, thus to the activation of the dorsal stream, and those who argue that off-line semantic information stored in memory (i.e., information mediated by the ventral system) might play a role in the elicitation of such effects. The finding that similar compatibility effects are observed also with words, that is during language processing of object words – where of course no information about object visual features is available – casts a doubt on the dorsal-only hypothesis (e.g., Tucker, Ellis, 2004; Derbyshire, Ellis, and Tucker, 2006; Borghi, Bonfiglioli, Ricciardelli, Rubichi, and Nicoletti, 2007). If, effectively, affordance effects are found also during processing of object words (or words that have an action significance), one cannot rule out a contribution of the ventral system and a mediation of long-term conceptual knowledge to the generation and explanation of affordance effects.

Alternatively, it might also be possible, as recently proposed, that there are two distinct routes within the dorsal stream, a pure dorso-dorsal route involved in ‘online’ visuomotor control, that is in transforming visual information into motor output, and a dorso-ventral route that includes semantic representations of objects and would encode the most common ways with which individuals interact with them (e.g., canonical and stable affordances) (Gentilucci, 2003).

In line with this hypothesis, and returning to the distinction between different kinds of affordances and their neural basis (Young, 2006), it has been suggested that stable affordances are represented more ventrally, whereas variable affordances are represented more dorsally. Specifically, it seems that variable affordances would activate predominantly the dorso-dorsal route, while stable affordances would activate primarily the dorso-ventral route of the dorsal pathway (Rizzolatti, Matelli, 2003; Sakreida, Menz, Thill, Rottschy, Eickhoff, Borghi, Ziemke, and Binkofski, 2013).

1.4 Research Overview

In the following three chapters, evidence will be presented to further support the notion that object names, like object pictures, can recruit the motor system and activate action-relevant object information in a way similar to that observed when individuals perceive or actually interact with their concrete referents. As discussed earlier, such a notion derives in large part from the embodied theories of language which highlight the close relationship that exists between perception, action, and cognition.

In chapter two, three experiments will be reported. As in most micro-affordance studies, in the first experiment a stimulus-response compatibility paradigm is employed to examine the presence of micro-affordance effects arising while observing and categorizing the pictures of manipulable common objects for which the action of either pinching or grasping is more appropriate. However, unlike these studies where objects were typically presented with their natural or real-world proportions preserved (i.e., objects that are usually picked up by pinching smaller than objects that are picked up by grasping), in this experiment the objects' on-screen size is balanced so that all objects, regardless of their real size, are displayed in approximately the same size. Such a manipulation has allowed to examine the degree to which the emergence of grasp compatibility effects depends on the processing of on-line visual features of objects.

In the second and third experiments, the same experimental design and stimuli are used as in the first experiment. This time, however, the names (written or spoken respectively) of the same objects displayed pictorially in experiment 1 were used in order to examine whether an object needs to be visually present and processed on-line for activating the motor programs associated with its affordances.

In addition, the use of the same experimental paradigm as well as of the same stimuli has allowed to make a direct comparison between the experiments, thus to examine how micro-affordance effects behave when objects are presented in different formats and through different sensory modalities.

In chapter three, two experiments will be described. In the first experiment reported (i.e., experiment 4), the same methodology and stimuli of experiment 3 are used. Participants are acoustically presented with a series of object names and asked to carry out a stimulus-response categorization task. At the same time, however, they are exposed to irrelevant visual stimulation, that is to a flickering random array of black and white dots on the screen termed dynamic visual noise (DVN) that has been shown to selectively interfere with individuals' visual processing (Quinn and McConnell, 1996). Such an interfering technique is used in this experiment in order to inhibit participants' capacity to visually imagine the objects to which words refer. In other terms, experiment 4 aims at ruling out the possibility that participants, while hearing an object name, can form a sort of visual mental image of its referent before making their responses.
While the first experiment is carried out to exclude the possibility - left open in previous studies - that visual mental imagery can intervene in the generation of micro-affordance effects observed with object names, the second experiment (i.e., experiment 5) aims at investigating the contribution of the semantic system to the elicitation of such effects by using a similar interfering paradigm. Again, as in experiment 2, participants are presented with a series of object written names and asked to carry out a stimulus-response categorization task. Meanwhile, however, they are acoustically exposed to an irrelevant speech (i.e., a reading from a book written in a language unknown to participants) in order to tax semantic processing.

In chapter four, two more experiments will be reported. In both experiments further evidence is sought for micro-affordance effects arising from the power and precision component of the grasping action. In the first experiment described (i.e., experiment 6), the experimental design employed is again based on a stimulus response compatibility paradigm. Again, participants are presented with the written names of manipulable objects and asked to carry out a stimulus-response categorization task. Unlike the previous experiments, however, the design has been slightly modified in order to introduce different stimulus onset asynchronies between the visual onset of the object name and the time point in which a response is required. Such a modification has been introduced in an effort to provide initial information about the time course with which affordance related motor activity develops during language processing of object names.

The second experiment reported (i.e., experiment 7), takes advantage of a different experimental methodology to examine whether semantic information about objects, once again accessed through their verbal labels, can be automatically translated into specific motor activity even when no response or movement at all is required. Specifically, single-pulse Transcranial Magnetic Stimulation (spTMS) has been administered to participants' primary motor cortex representation of the right hand, time locked to playing them a series of object written names presented on a screen. Simultaneously, electromyography (EMG) has been used to record muscular responses in the right hand. Additionally, as in experiment 6, different timings of stimulation relative to the onset of the object name have been introduced to further explore the temporal evolution of the action plans afforded by object names.

Finally, in the last chapter, a summary of the major experimental findings will be provided together with a final discussion on the main theoretical implications of the results presented.

Chapter Two

2.1 Introduction

In order to generate adaptive behaviour, the brain must figure out the most appropriate ways to interact with objects in the environment. The question of how the brain ascertains what interactions are appropriate for different objects is a major issue in the psychology of perception and action as well as in the field of neurosciences in general. As mentioned in chapter one, the ecological approach to perception (Gibson, 1979) has proposed that perceptual systems are naturally tuned to pick up on various objects' affordances. According to the affordance account, simply viewing an object can activate specific object-related motor plans. This notion finds support in a series of neuroimaging and behavioural studies showing that visual perception of objects is sufficient to partially activate motor representations. Such motor involvement has been taken as evidence that objects are represented in terms of the action they elicit (Grafton, Fadiga, Arbib, and Rizzolatti, 1997; Gallese, 2000; Chao and Martin, 2000; Gerlach et al., 2002; Grezes, Tucker, Armony, Ellis, and Passingham, 2003). On a behavioural level, this would imply that observing an object leads to the selection and activation of the movements aimed at appropriately and efficiently acting upon it (see, for example, Bub and Masson, 2010; Costantini, Ambrosini, Tieri, Sinigaglia, and Committeri, 2010; Ellis and Tucker, 2000; Tucker and Ellis, 1998, 2001, 2004). Indeed, this specific motor recruitment has often been demonstrated by means of the compatibility effects. It has been observed that the execution of an action while observing a manipulable object is influenced by the congruency of the action to the object. In other terms, a decrease in reaction times and/or in the percentage of errors (i.e., faster and more correct responses) has been found when participants execute a motor act congruent to that 'suggested' by the observed object. Such specific motor activations have been referred to as micro-affordances (Ellis and Tucker, 2000), that is action-relevant properties of objects whose representations are in part constituted by the partial activation of the motor patterns required to interact with them.

While these automatic motor activations and their resultant behavioural manifestations (i.e., affordance related compatibility effects) have been well documented, as described in the previous chapter, it is not entirely clear yet how and by what routes this kind of motor activity becomes active. In this regard, there is still an unsettled debate between those who assert that the compatibility effects observed between task-irrelevant object features and the motor acts used to perform the task are due exclusively to the activation of the dorsal stream, and those who argue that the ventral stream might play a role in the elicitation of such effects. Most authors hold that the neural counterpart of these effects is mainly represented by the activity of the dorsal system which, as reported earlier, has been considered responsible for online visuomotor control. More specifically, it has been conceived of as a network devoted to automatically transforming visual information into motor output with minimal influence from other systems, such as the ventral system (Goodale and Milner, 1992; Milner and Goodale, 1993). Indeed, a few sustainers of the dorsal-only hypothesis (see, for example, Goodale and Humphrey, 1998) assign the ventral system only a ‘guiding’ role in directing the dorsal system to a suitable target. They suggest that the ventral system, which is thought to be responsible for object recognition and to contain object semantic knowledge, could intervene when the dorsal system needs to be guided towards, for example, an appropriate part of an object to grasp. In such a case, manipulation (or functional) knowledge of the object could provide information about the appropriate object part to grasp, making this information available before a precise online dorsal parameterisation takes place during prehension (i.e., during the act of reach-to-grasp). In line with this view, it has been shown that when knowledge is required to direct the dorsal system to an appropriate object part to grasp and the semantic system is taxed by concurrent tasks that interfere selectively with semantic processing, also pertinent grasping movements towards the object are altered (Creem and Proffit, 2001).

This raises the question of how and to what extent the semantic system (i.e., long-term object-action knowledge) contributes to the generation of micro-affordance effects, and whether these motor patterns can be semantically activated without the necessity of an involvement of on-line dorsal processes.

The three experiments described in this chapter were undertaken in an effort to provide some answers to this question.

In each experiment evidence was sought for micro-affordance effects arising from the power and precision component of the grasping action.

Like in most micro-affordance studies, in the first experiment a stimulus-response compatibility paradigm was employed to examine the presence of micro-affordance effects arising while observing and categorizing the pictures of manipulable common objects. However, this time, the pictures' on screen size was manipulated so that all objects, regardless of their real-world size, were displayed in approximately the same size, thus no immediate visual information about objects' size was available. Such a manipulation has allowed to examine the degree to which the emergence of grasp compatibility effects depends on the processing of on-line visual features of objects.

In experiments two and three the names (visually or acoustically presented) of the same objects displayed pictorially in experiment 1 were used in order to examine whether an object needs to be visually present and processed on-line for activating the motor programs associated with its affordances, as would be expected if this mechanism were controlled mainly by on-line dorsal processes.

Using the same experimental paradigm as well as the same stimuli has allowed us to make a direct comparison between the experiments, thus to examine how micro-affordance effects behave when objects are presented in different formats and through different sensory modalities.

2.2 Experiment 1

2.2.1 Introduction

As reported earlier, in all the experiments presented in this thesis a stimulus-response compatibility paradigm was employed to examine the presence of micro-affordance effects arising from the power and precision component of the grasping action. Specifically, in the present experiment evidence was sought for grasp compatibility effects arising while observing and categorizing the pictures of manipulable common objects. The objects presented were either maximally compatible with a power grip (e.g., hammer, banana), or maximally compatible with a precision grip (e.g., tweezers, almond). Participants were asked to categorize each object presented as either naturally formed or manufactured. Depending on the mapping rule given, they had to press either a ‘power grip switch’ if the object was manmade or a ‘precision grip switch’ if the object was natural, and vice versa.

In contrast to most micro-affordance studies where objects were typically presented in roughly their natural or real-world size (e.g., ‘pinchable’ objects smaller than ‘graspable’ objects), in the present experiment the objects’ on-screen size was balanced so that all objects, regardless of their real size, were displayed in approximately the same size. As mentioned in the general introduction, the manipulation employed in the present experiment aimed at examining whether the activation of the motor programs associated with objects’ affordances relies more on the processing of their on-line visual properties or if it is due mainly to the influence of object conceptual information related to past visuomotor experiences stored in long term memory. In other words, the main purpose was to examine the contribution played by online, visual information (i.e., of information mediated by the dorsal system), and the contribution of off-line information stored in memory (i.e., of information mediated by the ventral system) in explaining the compatibility effects typically found in previous studies with different stimuli (e.g., Tucker and Ellis, 1998, 2001; Ellis and Tucker, 2000; Ellis, Tucker, Symes, and Vainio, 2007). If off-line semantic information plays a more important role than online visual information, then we should find an interaction between object graspability (graspable, pinchable objects) and the grip that the objects typically elicit (power, precision). More specifically, we expect to observe faster and more accurate power grasp responses to graspable objects (i.e., optimally compatible with a power grasp action) than to pinchable objects (i.e., optimally compatible with a precision grasp action), and faster and more accurate precision grasp responses to pinchable objects than to graspable ones. On the contrary, if online visual information is more important, then participants should respond on the basis of what they *see* (i.e., on the basis of the modified object size) rather than of what they *know* about object real-world size. In this case, a different pattern of results would be observed.

The emergence of compatibility effects between the size of objects and kind of response, independently from object displayed size, would suggest that the on-line processing of object visual features typically associated with the activity of the dorsal system is not the main source of the effects. Instead, this would lead to hypothesise that such effects might depend more upon stored semantic knowledge of the objects and their associated actions than upon the detailed physical properties of the viewed objects (see Tucker and Ellis, 2004 for a similar argument).

2.2.2 Method

Participants

Twenty four native British participants (14 females) aged between 18 and 32 years (Mean Age = 19.75; SD = 3.03) took part in the experiment. They were all right-handed (Mean Laterality Quotient = 83.08; SD = 16.52) as assessed by a revised version of the Edinburgh Handedness Inventory (Oldfield, 1971;

Williams, 1986; see *Appendix B*). Participants had normal or corrected-to-normal vision, and no motor function impairments were reported.

Prior to starting the experiment, informed consent was obtained from all participants who were naïve as to the purpose of the study. Each participant was paid £7 or received University credits for taking part.

The study was approved by the Psychology Department Ethical Committee of the University of Edinburgh and carried out in accordance with the ethical standards of the Declaration of Helsinki (1964).

Materials and Apparatus

The colour digital pictures (230 x 230 pixels) of 92 common objects comprised the stimulus set for this experiment. All objects had a hand-action significance: half had significance for the action of pinching and were optimally compatible with a precision grip (i.e., between thumb and index finger), whilst the other half had significance for the action of grasping and were optimally compatible with a power grip (i.e., whole hand grip). Within each category (pinchable and graspable objects), half the objects were natural, e.g. fruit, vegetables or nuts, and the other half were manmade, e.g. tools or utensils (see Appendix A for a complete listing of the stimuli used).

All objects were taken from the Bank of Standardized Stimuli (BOSS) (Brodeur et al., 2010), were matched for orientation[1] (i.e., each object appeared both right-oriented and left-oriented), and for size: namely, regardless of their natural size, all objects were presented in approximately the same size (~8 cm height). Object familiarity was checked according to the Snodgrass and Vanderwart’s (1980) picture norms (see Appendix A for more details). All pictures were displayed centrally on a 19’’ computer screen at a distance of approximately 50 cm.

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[1] The term ‘orientation’ is used here exclusively to refer to the slight inclination towards the right or left side of the object vertical midline.

Participants gave their responses by using a specially designed hand held device adapted from the Ellis and Tucker (2000) research study. It consisted of two components (see Figure 2.1).

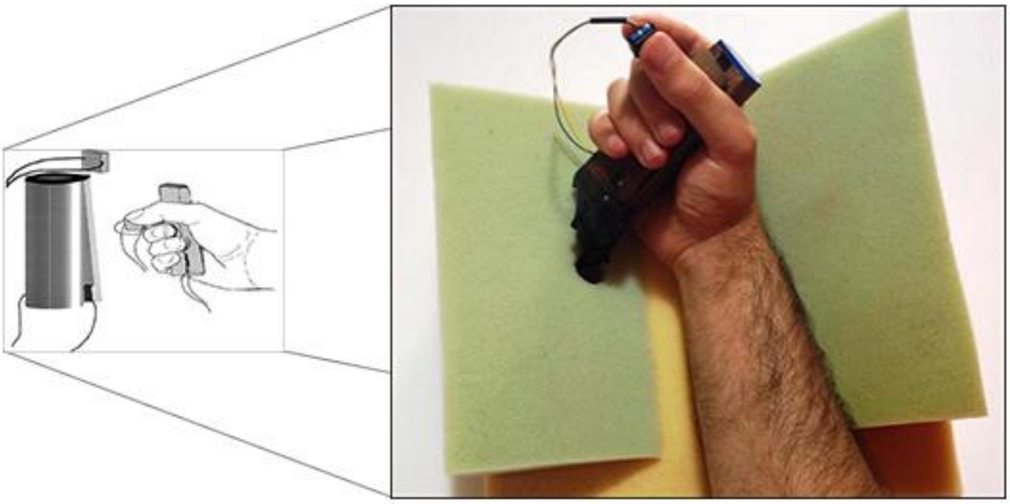

Fig. 2.1
Response Device

The first component was a wooden cylinder, roughly 10 cm tall and 1*8 cm in diameter to the side of which a section of wooden tubing was attached; it was hinged to the bottom of the cylinder, and between it and the cylinder there was a pressure switch. This section, thus, acted as a lever that caused the pressure switch to trigger when the hand squeezed the cylinder. The second component was a little pressure switch 1 cm square and 4 mm thick.

While keeping the right arm in a comfortable position on an inclined foam pad, participants held the device in their right hand (aligned with respect to the screen midline), grasping the little switch between thumb and forefinger, and the cylinder between the surface of the palm and the remaining three fingers, thus mimicking precision and power grips respectively.

Design and Procedure

The experiment was conducted in a sound attenuated and dimly illuminated room. It was implemented and controlled by E-Prime Software version 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA, 2009), which also allowed to record response types and times.

Prior to starting the experiment, participants were asked to fill in the revised version of the Edinburgh Handedness Inventory, and then to seat comfortably in front of the computer screen. Participants were instructed to hold their gaze on the centre of the screen all the time: a camera positioned in front of them allowed to check their gaze online during the entire experimental session, whilst a chin rest was used in order to avoid head movements. All participants were presented with written instructions (Appendix C), and completed 16 practice trials before commencement of the main experiment. Once they showed a good understanding of the experimental task (i.e., a performance score above 80%) and learned how to hold and use the hand device, the experiment started. As illustrated in Figure 2.2, a black fixation point at the centre of a white background signalled the start of each trial. Three hundred milliseconds (ms) later it was replaced by the target object, which remained in view for 2500 ms or until a response was made. Participants were instructed to decide whether the object was natural or manmade by making a response on the hand device. Half the participants were instructed to press the little switch between thumb and index finger (i.e., to make a precision response) for natural objects, and to squeeze the cylinder between the palm and the remaining three fingers (i.e., to make a power response) for manmade objects. The opposite mapping rule was used for the other half of the sample. Participants were asked to respond as fast as possible whilst maintaining accuracy. After responding, the object disappeared and was replaced by an inter-trial fixation point for 1000 ms. A blank white screen for 300 ms acted as a preparatory signal for the following trial.

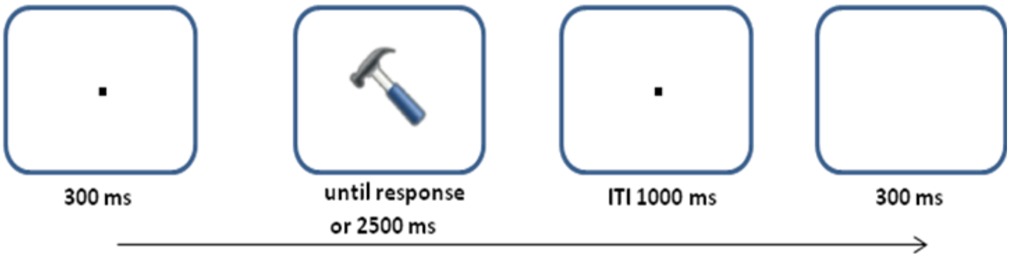

Fig. 2.2
Sequence of presentation in a typical experimental trial.

Overall, there were 368 trials (2 repetitions[2] of each picture x 46 stimuli per object category x 2 object categories x 2 object orientations) divided into eight blocks of 46 trials. At the end of each block, participants received a feedback for their performance on the screen**.** The order of trial presentation was completely randomized for each participant.

After the experimental session, all participants were debriefed and given a compensation for participating in the study.

2.2.3 Results

A maximum error rate of 10% was fixed for inclusion for participant data in this study. Based on this criterion, no participant was excluded from the analyses. Reaction times (RTs) more than two standard deviations from the participants' means were excluded from the analyses, and mean Rts were obtained using only correct trials. Mean correct Rts and mean percentage error rates were then entered into three-way mixed analyses of variance (ANOVA) with the Object Category (Graspability: pinchable, graspable), Response Type (Response: precision, power), as within participants factors, and Mapping (1: Natural = Precision Response; Manmade = Power Response/ 2: Natural = Power Response; Manmade = Precision Response) as a between participants factor.

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[2] As often reported in literature (e.g., Gough et al., 2011; Ferri et al., 2011; Makris et al., 2011), the stimuli presentation was repeated (i.e., each stimulus was presented twice) to ensure a sufficient number of trials to analyse.

All data were analysed using *SPSS®* version 19.0 (*SPSS* Inc., Chicago, IL, USA).

Response Time Data

The analysis for the mean RTs revealed a significant two-way interaction between Graspability and Response [F (1,22) = 5.08; p = .034; η_P^2 = .188]. This interaction is illustrated in Fig. 2.3.

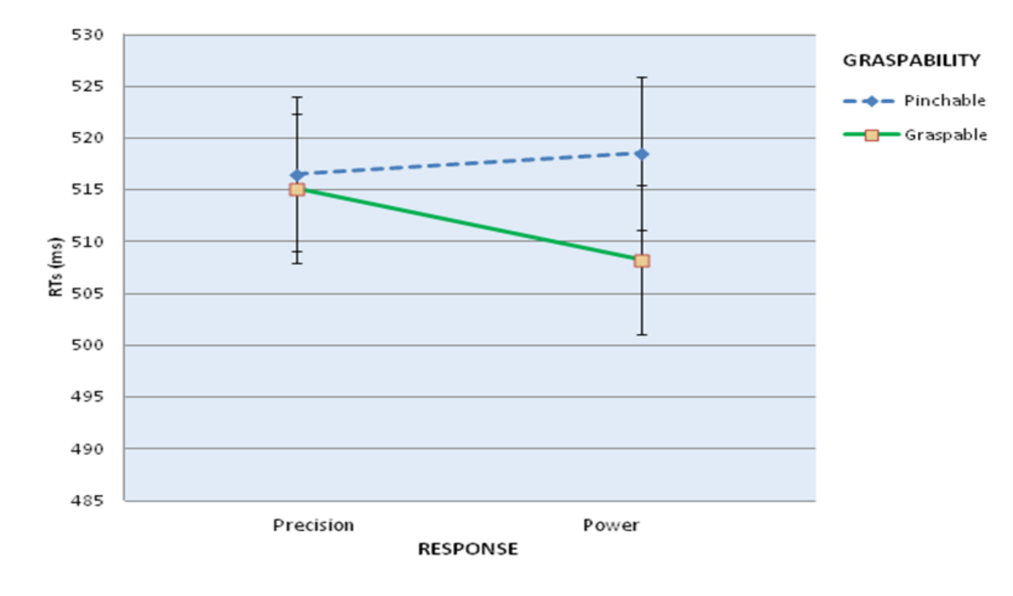

Figure 2.3

Mean Response Times for Power and Precision Responses to Graspable and Pinchable Objects. Error bars denote standard errors.

Student-Newman-Keuls (S-N-K) post-hoc analyses showed that in the power response condition responses were executed faster for compatible graspable objects (M = 508.2; SD = 37.2) than for incompatible pinchable objects (M = 518.4 ; SD = 37.4). However, this compatibility effect was not observed in the precision response condition where responses seemed to be only slightly faster for compatible pinchable objects (M = 515.06; SD = 47.2) than for incompatible graspable ones (M = 516.05; SD = 43.5).

A significant interaction was also observed between Response and Mapping [F (1,22) = 25.97; p = .000; η_P^2 = .541] (See Fig. 2.4 below).

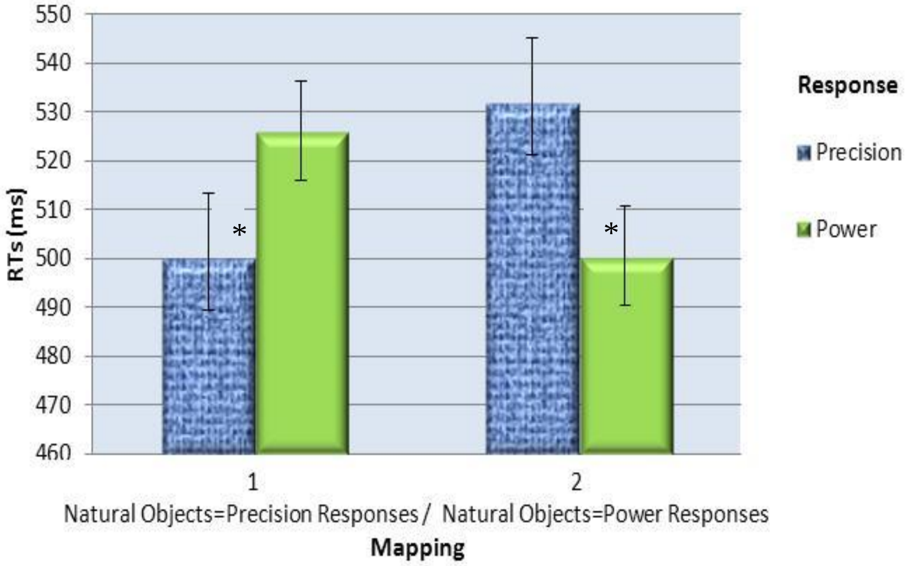

Figure 2.4

Mean Response Times for Power and Precision Responses to Graspable and Pinchable Objects in Mapping Condition 1 and 2. Error bars denote standard errors.

S-N-K post-hoc tests revealed that in mapping condition one precision responses were executed faster (M = 499.89; SD = 46.89) than power responses (M = 526.06; SD = 34.83). In mapping condition two the opposite pattern could be observed. Power responses were executed faster (M = 500.63; SD = 35.10) than precision responses (M = 531.66; SD = 36.72). Since in mapping condition one participants were asked to respond to natural objects with a precision grip, whereas, in mapping condition two participants were asked to respond to natural objects with a power grip, one could interpret this interaction in terms of overall faster response times to naturally formed objects. A similar finding has been reported elsewhere in the literature (e.g., Ellis and Tucker, 2000; Derbyshire et al., 2006; Borghi et al., 2007; Anelli et al., 2010; Gerlach, 2009; Ferri et al., 2011). Specifically, it has been shown that, in categorization tasks, responses to manufactured objects tend to be slower than responses to natural objects. Such slowing down of reaction times has been explained as being due to the fact that probably, compared to natural objects, artifacts or tools activate - in addition to manipulation knowledge - even functional information (i.e., how to use an object) (e.g., Warrington and Shallice, 1984) that interferes with task responses (but see also error data results).

Contrary to what has often been reported in previous studies (see, for instance, Tucker and Ellis, 2001; Derbyshire et al., 2006), the main effect of Graspability did not reach significance [F (1,22) = 3,242; p = .082]. In particular, more commonly it has been observed that, overall, responses to graspable objects are executed faster than responses to pinchable objects. This effect has been explained by the visual salience of the object category: graspable objects are responded to faster probably because they are larger than pinchable objects, therefore more easily accessible. In line with this explanation, in the present experiment this effect reduced probably because both graspable and pinchable objects were displayed in approximately the same size.

In order to test whether object orientation had had an impact on the pattern of results observed, and in particular on participant’s performance when they were exposed to either natural or manmade objects a further ANOVA was conducted. Since object type represented the relevant feature of the stimuli according to which they had to be categorized by making a different (and opposite) response based on the mapping rule given, the most appropriate way to analyze data was to divide participants’ responses into ‘grasp compatible’ and ‘grasp incompatible’ trials in order to obtain the new factor ‘Compatibility’ resulting from collapsing across the levels of the Graspability and Response factors. Participant’s responses were then entered into a three-way repeated measures ANOVA with

Compatibility (compatible, incompatible trials), Orientation (right, left), and Object Type (natural, manmade) as within participants factors. The analysis revealed a main effect of Object Type [F (1,23) = 26.770; p = .000; η_p^2 = .538], confirming that participants tended to categorize natural objects (M = 500.30; SD = 40.63) faster than manmade objects (M = 528.82; SD = 35.13) overall. On the contrary, the analysis failed to reveal a main effect of Orientation [F (1,23) = .524; p = .476], as well as significant interactions between this factor and both Object Type [F (1,23) = 0.27; p = .872] and Compatibility [F (1,23) = .344; p = .563] or a significant three way interaction [F (1,23) = 2.140; p = .157]. This suggests that participants' performance in general, and in particular the compatibility effects observed, did not change across the conditions examined (see discussion).

Error Data

The pattern resulted from the analysis applied to mean percentage error rates was similar to that observed in response time data. Again, a significant two-way interaction between Graspability and Response [F (1,22) = 5.10; p = .034; η_p^2 = .188] was found. This interaction is illustrated in Fig. 2.5. S-N-K post-hoc analyses showed that participants responded significantly more accurately to graspable objects with a compatible power response (M = 2.21% ; SD = 1.98) than with an incompatible precision response (M = 3.62% ; SD = 2.57). This was not the case for pinchable objects. For these stimuli only a small difference between power (M = 2.84%; SD =2.42) and precision (M = 2.92%; SD =2.16) responses was found. However, it has to be said that in the precision response condition participants tended to respond more accurately to them (M = 2.92% ; SD =2.16) than to graspable objects (M = 3.62% ; SD = 2.57).

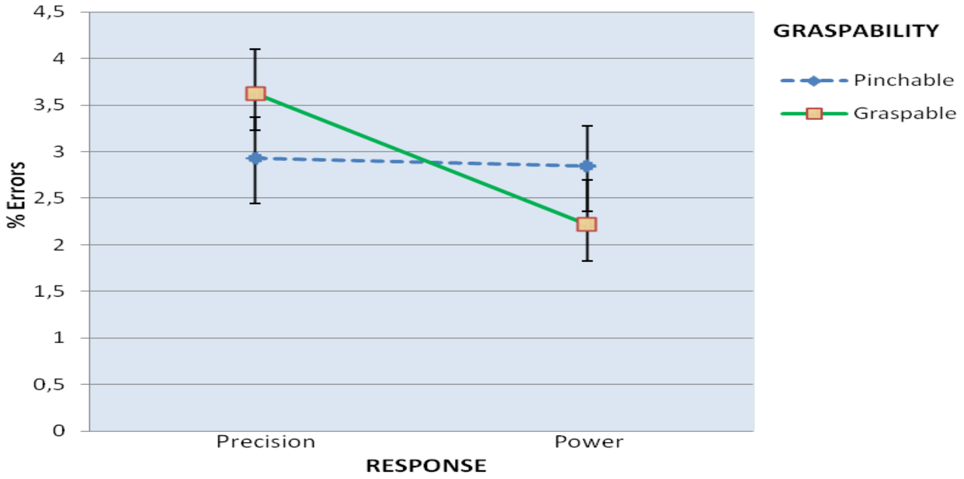

Figure 2.5

Mean Percentage of Errors for Power and Precision Responses to Graspable and Pinchable Objects. Error bars denote standard errors.

Moreover, the interaction between Response and Mapping was still significant in error data [F (1,22) = 9.44; p = .006; η_P^2 = .300] (see Fig. 2.6 below).

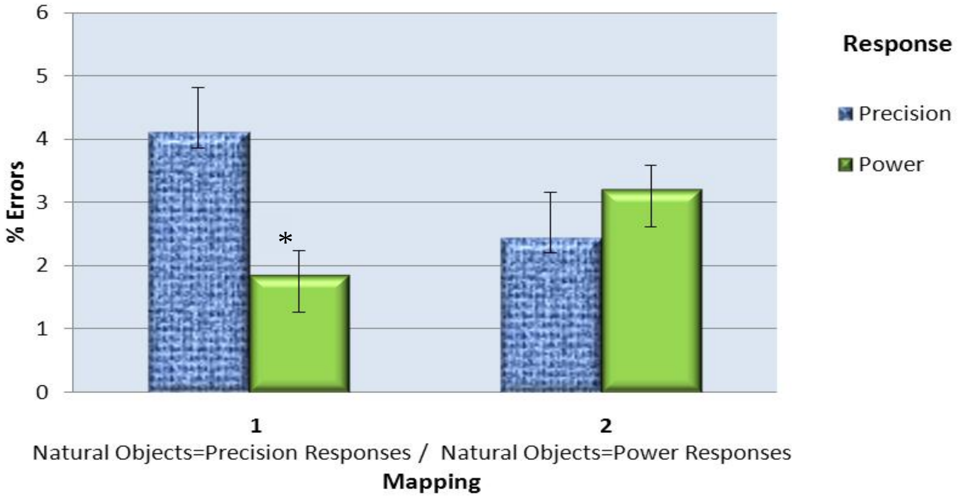

Figure 2.6

Mean Percentage of Errors for Power and Precision Responses to Graspable and Pinchable Objects in Mapping Condition 1 and 2. Error bars denote standard errors.

This time, S-N-K post-hoc tests revealed that in mapping condition one (Natural = Precision Response; Manmade = Power Response) participants made significantly more errors in the precision response condition (M = 4.10%; SD = 2.46) than in the power response condition (M = 1.85%; SD = 1.34). In mapping condition two (Natural = Power Response; Manmade = Precision Response) there was only a small difference between the percentage of errors in the power response condition (M = 3.20%; SD = 2.04) and that observed in the precision response condition (M = 2.44%; SD = .85). As is apparent, this pattern of results was likely driven by a speed-accuracy trade off. As observed in the reaction time data, participants tended to respond faster to natural objects, and this probably led them to commit more errors in response to this kind of objects.

The analysis did not show other significant interactions or main effects.

As for Rts data, a further ANOVA was conducted for error data to analyse participant’s responses to right and left oriented objects when they were exposed to either natural or manmade stimuli. The analysis showed the same pattern of results emerged in the complementary three-way repeated measures ANOVA applied to mean RTs. A main effect of Object Type was found [F (1,23) = 12.616; p = .002; η_p^2 = .354], with participants categorizing manmade objects (M = 2.15; SD = 1.13) more correctly than natural objects (M = 4.07; SD = 2.42). The main effect of Orientation was not significant [F (1,23) = 1.123; p = .300], as well as the interactions between this factor and both Object Type [F (1,23) = .013; p = .911] and Compatibility [F (1,23) = 617; p = .440]. As in Rts data, no significant three-way interaction was found [F (1,23) = .569; p = .458].

2.2.4 Discussion

The results of experiment 1 are consistent with the results of previous studies which report micro-affordance effects for seen objects associated with a power or precision response. Similarly to what emerged in these studies, in the present experiment significant interactions were observed between Graspability and Response in both the response time data and in error data, indicating faster and more correct responses to 'response compatible trials' compared to 'response incompatible' ones. The results emerged confirm that visual objects lead to internally 'simulate' grasping actions and are able to activate congruent motor information on how to manipulate them. However, the grasp compatibility effects observed seemed to be clearer for power responses than for precision ones. This was probably due to the fact that, in real life, grasping an object with a whole hand grip is easier than grasping an object with a precision grip as the precision posture is more linked to fine prehension (Ehrsson et al., 2000), which developed only later during evolution and, thus, might require the involvement of more complex processing mechanisms. In addition, the affordance effect found seemed to be linked only to a more stable feature of objects (i.e., their size), whilst no compatibility effects were found with respect to object orientation. Specifically, no differences were found in participant's performance when they were exposed to either right- or left-oriented objects. At first glance, this seems to be at odds with some results reported in literature indicating clear congruency effects between the position (right-left) of object handles and responding hand (e.g. Tucker and Ellis, 1998; see also Buccino, Sato, Cattaneo, Rodà, and Riggio, 2009). For example, as reported in the first chapter, Tucker and Ellis (1998) found that right-hand responses to objects with handles oriented to the right are faster and more accurate than right-hand responses to objects with handles oriented to the left. Similarly, they found that left-hand responses to objects with handles oriented to the left are faster and more accurate than left-hand responses to objects with handles oriented to the right. Actually, the apparent contradiction between our results and what is reported in literature reduce if it is considered the different way through which object orientation was obtained in experiment 1. Differently from previous studies, the orientation of the stimuli employed here did not involve the position of their handles but only the inclination towards the right or left of their vertical midline. Probably, in this case, there was not a real incongruence between orientation-related grasping affordances and responding hand as objects could be able to afford a right–hand response both when inclined towards the right and when inclined towards the left.

More importantly, the present results suggest a substantial role of the off-line object semantic information in explaining affordance-related compatibility effects. In this experiment the fact that both large (i.e., graspable) and small (i.e., pinchable) objects were not displayed with their real-world proportions preserved, thus with no immediate visual differences in size, seemed not to influence participant's performance. As shown by the interaction between type of object and type of response, participants seemed to categorize the stimuli presented not on the basis of how objects appeared visually but on the basis of what they knew about them. In other words, participants seemed to ignore the modified size of objects and to respond on the basis of their real-world size. This suggests that the on-line processing of an object's visual properties might not be a necessary requirement for affordance compatibility effects to be induced. Instead, the process responsible for their generation seems to be linked more to the objects' off-line representations and the associated action-related knowledge than to the specialised on-line visuomotor processes mediated by the dorsal system. Another attempt to investigate the contribution of the dorsal and ventral systems to the generation of grasp compatibility effects by manipulating the size of objects comes from a study by Bazzarin et al. (2007). In their study, participants had to categorize photographs of common objects manipulable with either a power or a precision grip into manmade or natural by making either a right or left hand key press response. Target-objects were preceded by primes consisting of photographs of two hand grasping postures (power, precision) and one neutral posture (closed hand). Target-objects could be presented either in their real size or in a modified size. In the latter condition, the objects typically affording a precision grip were zoomed out (e.g., a nut was enlarged to an orange size), whilst the objects usually affording a power grip were zoomed in (e.g., an apple was resized to become as small as a cherry). In each trial the objects were presented close to a 50cent coin in order to allow participants to understand whether the object was presented in its real or modified size. The authors found a significant interaction between object size (real, modified) and object type (graspable, pinchable). Specifically, they found that in the real size condition graspable objects were processed significantly faster than pinchable objects, whilst in the modified size condition the pattern was reversed as pinchable objects presented with enlarged dimensions tended to be processed faster than graspable objects presented with reduced size. According to the authors, the pattern of results observed depends mainly on object online visual information, and thus on the activity of the dorsal system, even in a categorization task in which the ventral system (i.e., semantic knowledge) is necessary involved. They argue that if results depended more on off-line semantic information, then no difference should be found between conditions, namely graspable objects should be processed faster than pinchable objects, independently from their modified size. However, their study failed to show a grasp compatibility effect between the hand prime and the type of object similar to that emerged in our experiment between type of response and type of object. This different pattern of results can be explained taking into account the methodological differences between the studies. For instance, in the study described above participants were simply asked to give speeded button press responses with their left and right hand, thus a compatibility effect could emerge only as a consequence of the congruency between the object type (graspable, pinchable) and the pictures of different hand postures (power, precision grips). In our study, the fact that participants had to categorize objects by mimicking precision and power grasps that had a more exact mapping to object affordances might have created a ‘motor resonance’ between objects and responses strong enough to allow the elicitation of grasp compatibility effects. Another important difference concerns the object size manipulation. In our study, all objects were displayed in the same size, thus no visual information about object size was available. On the contrary, in their study pinchable objects were displayed as large as graspable objects, whilst graspable objects were presented as small as pinchable objects. The particular manipulation employed by the authors might have generated a conflict between object semantic information mediated by the ventral system (i.e., object real size) and object on-line visual information (i.e., object modified size), which might have caused in turn the absence of compatibility effects. In addition, the fact that all objects were presented next to a 50cent coin might have caused an interference between the type of grasp potentially afforded by the coin (i.e., a precision grasp) and the type of grasp afforded by the target-objects (see Cisek's affordance competition model, 2007).

In summary, the results of experiment 1 confirm previous theories and studies that assume that all objects present motor information and are able to activate specific motor plans congruent with those that would be required to manipulate them. However, our results additionally suggest that this specific motor activation might rely mainly on off-line semantic knowledge about objects stored in long-term memory and mediated by the ventral system.

2.3 Experiment 2

2.3.1 Introduction

As a stronger test of the hypothesis that the on-line processing of an object's visual features might not be a necessary requirement for activating the motor programs associated with its affordances, the written names of the objects presented pictorially in the previous experiment were used for experiment 2. Here of course, no immediately action-related visual input was present, thus, if the compatibility effects previously found between object type and response type depend mainly on the activation of object representations stored in memory and if there is no necessity for an object to be currently present and visually processed to induce such effects, then object words should be able to elicit a pattern of results similar to that observed with object pictures in experiment 1.

2.3.2 Method

Participants

Twenty four new participants (16 females) aged between 18 and 35 years (Mean Age = 22.29; SD = 4.31) took part in the experiment. They were all native British English speakers and right-handed (Mean Laterality Quotient = 88.80; SD = 11.05) as assessed by a revised version of the Edinburgh Handedness Inventory (Oldfield, 1971; Williams, 1986; see *Appendix B*). Participants had normal or corrected-to-normal vision, and no reading or motor function impairments were reported.

Prior to starting the experiment, informed consent was obtained from all participants who were naïve as to the purpose of the study. Each was paid £7 or received University credits for taking part.

The study was approved by the Psychology Department Ethical Committee of the University of Edinburgh and carried out in accordance with the ethical standards of the Declaration of Helsinki (1964).

Materials and Apparatus

The written names of 92 common objects (the same used in experiment 1) comprised the stimulus set for this experiment. Object names were checked for lexical frequency (CELEX English lexical database, version 2.5), word familiarity and imageability (Bristol norms, Stadthagen-Gonzalez and Davis, 2006). Overall, the mean syllables number of the object names was 1.95 (SD = .73), whilst the mean letters length was 6.25 (SD = 1.93). Most importantly, the mean letter length of the power compatible object names (M = 6.26; SD = 1.93) did not differ from the mean letter length of the precision compatible object names (M = 6.23; SD = 1.94). All stimuli were presented centrally on a 19'' computer screen at a distance of approximately 50 cm.

Participants gave their responses by using the same response apparatus used in experiment 1.

Design and Procedure

The same experimental design and procedure used in the previous experiment were employed for the present experiment. Figure 2.7 shows the sequence of presentation in a typical experimental trial.

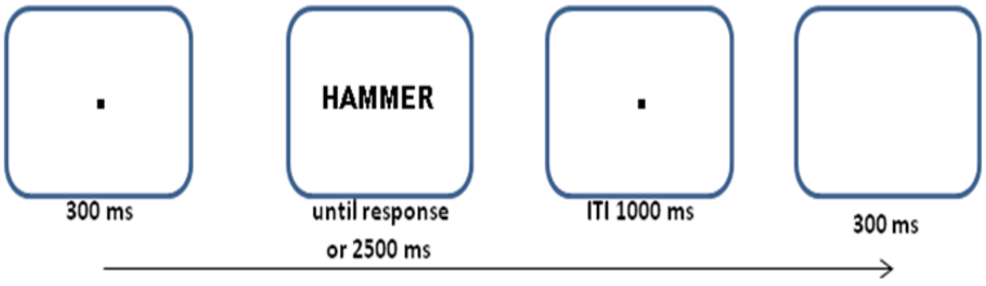

Fig. 2.7

Sequence of presentation in a typical experimental trial.

As in the previous experiment, each stimulus was presented twice and two slightly different fonts[3] (Arial, Comic Sans MS) were used. As a whole, there were 368 trials (2 repetitions of each object name x 46 stimuli per object category x 2 object categories x 2 fonts) divided into eight blocks of 46 trials.

2.3.3 Results

A maximum error rate of 10% was fixed for inclusion for participant data in this study. Based on this criterion, two participants were excluded from the analyses. RTs more than two standard deviations from the participants' means were excluded from the analyses, and only correct trials were used to create mean Rts. Mean correct Rts and mean percentage error rates were then entered into three-way mixed ANOVAs with Graspability (pinchable, graspable), Response (precision, power) as within participants factors, and Mapping (Natural = Precision Response; Manmade = Power Response / Natural = Power Response; Manmade = Precision Response) as a between participants factor.

Response Time Data

The analysis for the mean RTs revealed a pattern of results very similar to that observed in experiment 1. Again, a significant two-way interaction between Graspability and Response was found [F (1,20) = 14.021; p = .001; η_p^2 = .412]. This interaction is illustrated in Fig. 2.8.

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[3] Given that in experiment 1 the stimuli employed appeared both right and left oriented, in the present experiment we wanted to make sure that the stimuli continued to be displayed with a visual difference, namely the object names were now presented in two different fonts. This methodological choice was taken in order to hold the conditions of stimuli presentation as constant as possible across experiments. Furthermore, since the stimuli were repeated several times, the slight variation of their perceptual features aimed at reducing possible effects of habituation that could emerge during the experiment.

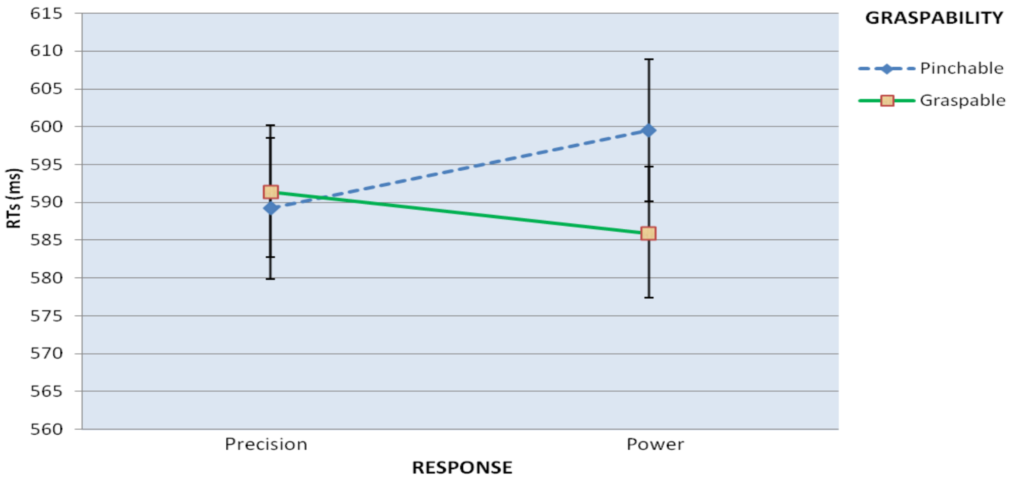

Figure 2.8

Mean Response Times for Power and Precision Responses to Graspable and Pinchable Objects. Error bars denote standard errors.

S-N-K post hoc tests showed that in the power response condition responses were executed faster for compatible graspable objects (M = 584.3; SD = 42.4) than for incompatible pinchable objects (M = 598.2; SD = 44.9). This grasp compatibility effect did not emerge in the precision response condition where responses to pinchable objects (M = 591.02; SD = 47.2) were only slightly faster than responses to graspable objects (M = 593.03; SD = 44.6). However, participants seemed to respond faster to graspable objects with a power response (M = 584.3; SD = 42.4) than with a precision response (M = 593.03; SD = 44.6), and to pinchable objects with a precision response (M = 591.02; SD = 47.2) than with a power response (M = 598.2; SD = 44.9).

As in experiment 1, a significant interaction was also observed between Response and Mapping [F (1,20) = 31.032; p = .000; η_p^2 = .608]. S-N-K post hoc analyses confirmed that in mapping condition one precision responses were executed faster (M = 570.97; SD = 50.36) than power responses (M = 608; SD = 47.17). In mapping condition two the opposite pattern could be observed. Power responses were executed faster (M = 577.40; SD = 34.61) than precision responses (M = 609.57; SD = 33.19). Since in mapping condition one participants were asked to respond to natural objects with a precision grip, whereas, in mapping condition two participants were asked to respond to natural objects with a power grip, again this interaction can be interpreted in terms of overall faster response times to naturally formed objects. The same increase of reaction times for manufactured objects was reported in the previous experiment with object pictures and has been explained as being due to the fact that probably, compared to natural objects, manmade objects recruit the motor resources to a greater extent by activating both manipulation and functional object knowledge. This, in turn, would generate an interference with the motor program necessary to accomplish the task and the consequent slowing down of reaction times.

No other interactions or main effects were found to be significant. In particular, it can be noted that even in the present experiment the analysis for the mean RTs showed that the main effect of Graspability failed to reach significance [F (1,20) = 3.780; p = .065]. In other words, differently from what has been reported in literature, the present data do not seem to reveal a processing advantage of graspable (i.e., large) over pinchable (i.e., small) objects. If, once again, one takes into account the ‘object visual salience’ explanation, the lack of such effect can be explained by the fact that in the present experiment objects’ names were used as stimuli, thus no immediate visual information about objects’ physical properties could be available.

However, it has to be said that a similar processing advantage has been reported even for words referring to large objects compared to words referring to small objects (see, for example, Sereno et al., 2009).

Error Data

The pattern resulted from the analysis applied to mean percentage error rates was similar to that observed in response time data. A significant two-way interaction between Graspability and Response was found [F (1,20) = 8.722; p = .008; η_p^2 = .304]. This interaction is illustrated in Fig. 2.9.

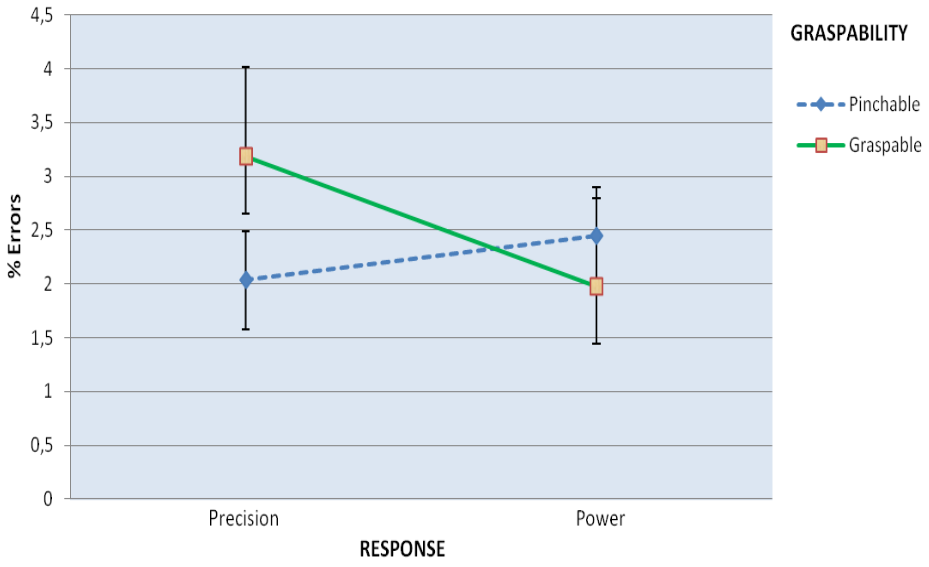

Figure 2.9

Mean Percentage of Errors for Power and Precision Responses to Graspable and Pinchable Objects. Error bars denote standard errors.

S-N-K post hoc analyses showed that participants responded more accurately to graspable objects with a compatible power response (M = 2.02%; SD = 2.49) than with an incompatible precision response (M = 3.21%; SD = 3.77). Similarly, pinchable objects tended to be responded to more accurately with a compatible precision response (M = 2.02%; SD = 2.07) than with an incompatible power response (M = 2.56%; SD = 2.50), although not significantly.

There was a significant three-way interaction between Graspability, Response and Mapping [F (1,20) = 4.672; p = .043; η_p^2 = .189]. Separate 2 (Graspability) x 2 (Response) ANOVAs were run for each of the two different mappings. The analyses showed a significant interaction between Graspability and Response only for the mapping condition two (Natural = Power Response;

Manmade = Precision Response) [F (1,11) = 11.759; p = .006; η_P^2 = .517]. This interaction is illustrated in Fig. 2.10.

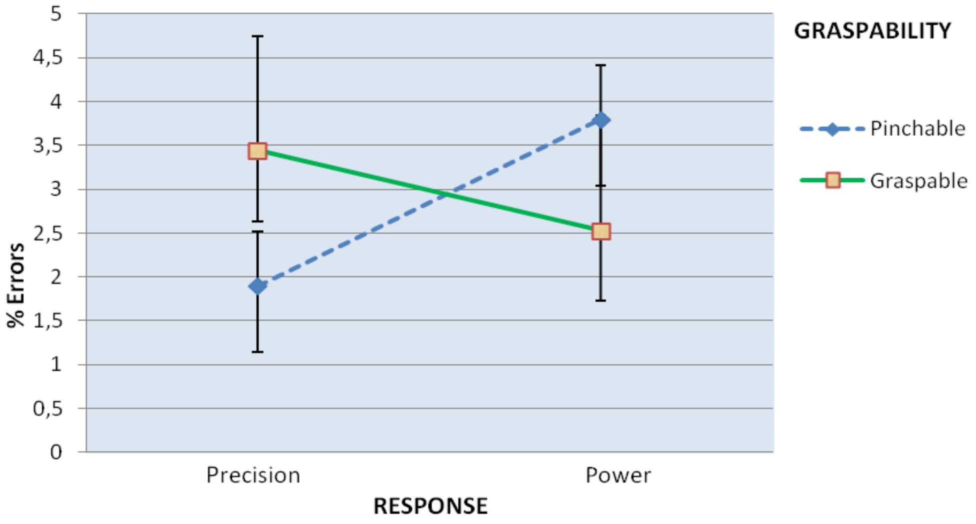

Figure 2.10

Mean Percentage of Errors for Power and Precision Responses to Graspable and Pinchable Objects in Mapping Condition Two (Natural = Power Response; Manmade = Precision Response). Error bars denote standard errors.

For this mapping condition, S-N-K post hoc tests revealed that participants responded significantly more accurately to pinchable objects with a compatible precision response (M = 1.90% ; SD = 2.13) than with an incompatible power response (M = 3.80% ; SD = 2.64). Similarly, graspable objects tended to be responded to more accurately with a compatible power response (M = 2.53% ; SD = 2.79) than with an incompatible precision response (M = 3.44%; SD = 4.53).

No obvious explanation can be offered for the lack of interaction in mapping condition one.

No other interactions or main effects were found to be significant.

2.3.4 Discussion

The results of experiment 2 are consistent with those of experiment 1. They indicate that grasp compatibility effects can emerge whether or not an object is being seen or identified through its verbal label. Specifically, it was found that power responses to the words that refer to power grasp compatible objects are executed faster and more accurately than power responses to the words that refer to precision grasp compatible objects. Similarly, the names of precision compatible objects were responded to faster and more accurately with a precision response than with a power response.

It seems that the identification of an object, through either its picture or its name, is sufficient to activate appropriate object representations and the associated motor responses. This finding suggests that the concurrent presence of a visual object is not necessary to prime a particular type of grasp, and that the process responsible for the generation of affordance-based motor priming does not always depend on the transient on-line visuomotor processing associated with the activity of the dorsal pathway. Rather, what appears to be critical for the expression of such effects are long-term object-action associations that are known to be under the remit of the ventral pathway. This issue will be discussed further in the general discussion at the end of this chapter.

2.4 Experiment 3

2.4.1 Introduction

Taken together, the results emerged from the previous experiments suggest that object representations activated both during the observation of the picture of a manipulable object (experiment 1) and the lexical processing of its written name (experiment 2) are able to potentiate actions arising from the power and precision components of the grasping action, and that the congruency effects observed might rely mainly on object semantic knowledge, namely on the activity of the ventral system.

The hypothesis that object representations can be activated as soon as objects are identified, independently from the nature of the source of activation, finds support in a series of functional neuroimaging studies showing that object representations can be automatically accessed upon identification, regardless of format (pictures, words) or sensory modality (visual, auditory) through which objects are presented (for reviews, see Bookheimer, 2002; Martin and Chao, 2001; Thompson-Schill, 2003; Martin, 2001, 2007). These studies indicate that a common neural substrate is active during conceptual processing of both object pictures and object words. In particular, two key regions of the brain have been individuated: left ventrolateral prefrontal cortex and the ventral and lateral regions of posterior temporal cortex, with activations typically stronger in the left than in the right hemisphere. As is evident, such a circuit corresponds, to a large extent, to the neural ventral pathway previously described. So far, our studies have provided additional support for this hypothesis only in part as they indicate, with a different research technique, that object representations, and the associated action-related information, can be automatically activated independently from the format (pictures, words) through which objects are presented. In order to analyse what happens when objects are presented through a different sensory modality, the same stimuli presented visually in the previous experiments were presented acoustically in experiment 3. If, as discussed earlier, the activation of object representations and the associated motor information mainly relies on identifying the object, independently from format or sensory modality through which they are accessed, then a pattern of results similar to that observed in the previous experiments was expected to be found.

The choice of employing auditory stimuli for experiment 3 was useful also for a methodological reason concerning the following experiment. As will be described in details in chapter 3, in experiment 4 participants were exposed to a form of visual stimulation in order to interfere selectively with their visual imagery capacity. Since their task had to consist of categorizing object names into natural or manmade, the use of spoken names appeared the most appropriate for that particular experimental set-up. Furthermore, given that all conditions (except the visual interference) remained unvaried across experiments, participants' performance obtained in experiment 3 was used as a control for that obtained in experiment 4.

2.4.2 Method

Participants

Twenty four new participants (17 females) aged between 18 and 34 years (Mean Age = 21.91; SD = 4.42) took part in the experiment. They were all native British English speakers and right-handed (Mean Laterality Quotient = 91.92; SD = 16.11) as assessed by a revised version of the Edinburgh Handedness Inventory (Oldfield, 1971; Williams, 1986; see *Appendix B*). Participants had normal or corrected-to-normal vision, and no reading, hearing or motor function impairments were reported.

Prior to starting the experiment, informed consent was obtained from all participants who were naïve as to the purpose of the study. Each participant was paid £7 or received University credits for taking part.

The study was approved by the Psychology Department Ethical Committee of the University of Edinburgh and carried out in accordance with the ethical standards of the Declaration of Helsinki (1964).

Materials and Apparatus

The names of 92 common objects (the same used in experiment 2) comprised the stimulus set for this experiment. This time, however, each stimulus[4] was presented acoustically through headphones.

Participants gave their responses by using the same manipulandum employed in the previous experiments, which was able to mimick precision and power grips (see Fig. 2.1).

Design and Procedure

The experimental design and procedure employed for the present experiment were the same of those used in the previous experiments. Figure 2.11 below shows the sequence of presentation in a typical experimental trial.

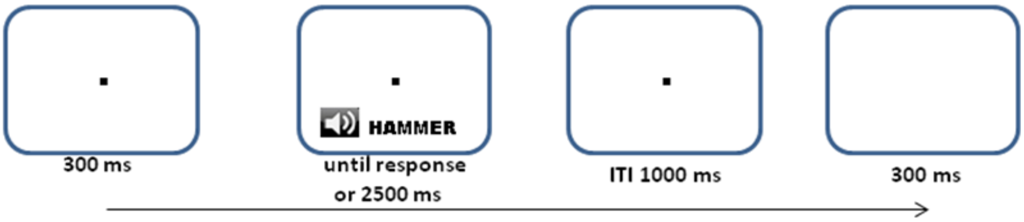

Fig. 2.11

Sequence of presentation in a typical experimental trial

As in the previous experiments, a black fixation point at the centre of a white background signalled the start of each trial. Three hundred ms later the digital recording of one of the 92 object names was delivered through a pair of headphones for its own duration[5]. Meanwhile, participants kept their gaze on a

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[4] For the creation of the stimulus set, two actors (one man and one woman) were asked to read each object name while being recorded in a sound recording studio. This allowed to obtain a clear digital recording for each of the 92 stimuli used in the experiment.

[5] Overall, the mean duration of the digital recordings was 674.65 ms (SD = 114.14). Most importantly, the mean duration of the digital recordings referring to power compatible object names (M = 683.48; SD = 117.55) did not differ from the mean duration of the digital recordings referring to precision compatible object names (M = 665.81; SD =111.21).

black fixation point, which remained in view for 2500 ms or until a response was made. Depending on the mapping rule given, participants' task was to decide whether the name referred to a natural or manmade object and to respond by making a power or a precision response on the hand device. After responding, an inter-trial fixation point appeared for 1000 ms. A blank white screen for 300 ms acted as a preparatory signal for the following trial.

Each stimulus was presented twice, and both the voices[6] (Male, Female) were used. Overall, there were 368 trials (2 repetitions of each object name x 46 stimuli per object category x 2 object categories x 2 voices) divided into eight blocks of 46 trials.

2.4.3 Results

A maximum error rate of 10% was fixed for inclusion for participant data in this study. Based on this criterion, no participant was excluded from the analyses. RTs more than two standard deviations from the participants' means were excluded from the analyses, and mean Rts were obtained using only correct trials. Mean correct Rts and mean percentage error rates were then entered into three-way mixed ANOVAs with Graspability (pinchable, graspable), Response (precision, power) as within participants factors, and Mapping as a between participants factor.

Response Time Data

The analysis for the mean RTs showed a pattern of results consistent with that observed in the previous experiments. Once again, a significant two-way interaction between Graspability and Response was found [F (1,22) = 7.878; p =

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[6] Like in the previous experiment, we decided to present the stimuli with a physical difference (i.e., two different voices) in order to keep the conditions of stimuli presentation constant as much as possible across experiments, and to avoid possible effects of habituation due to repeated presentations of the stimuli.

.010 η_P^2 = .264]. This interaction is illustrated in Fig. 2.12. S-N-K post hoc analyses showed that in the power response condition responses were executed significantly faster for graspable objects (M = 799.6; SD = 76.09) than for pinchable objects (M = 808.4; SD = 73.9). Likewise, in the precision response condition responses were executed significantly faster for pinchable objects (M = 791.3; SD =67.6) than for graspable objects (M = 800.1; SD = 71.4).

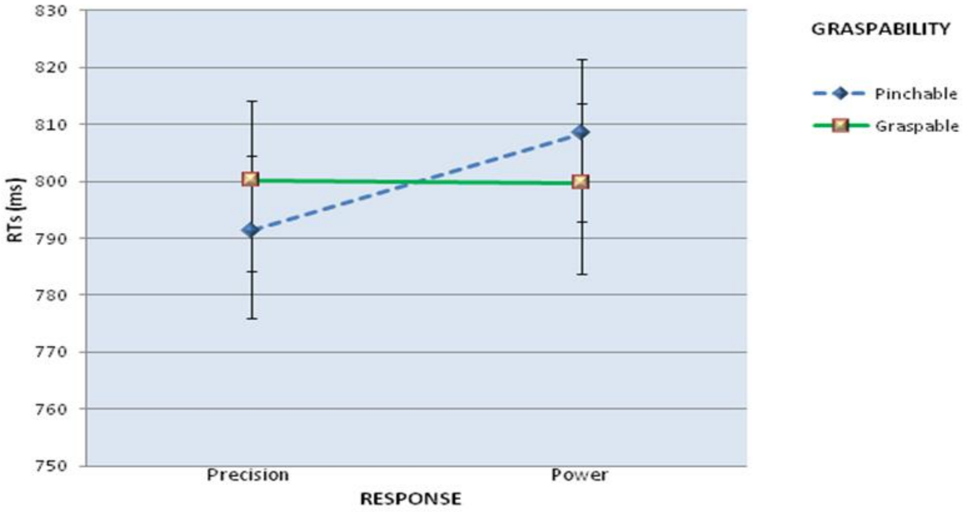


Figure 2.12

Mean Response Times for Power and Precision Responses to Graspable and Pinchable Objects. Error bars denote standard errors.

As in the previous experiments, a significant interaction was observed between Response and Mapping [F (1,22) = 16.353; p = .001 η_P^2 = .426]. S-N-K post hoc tests revealed that in mapping condition one precision responses were executed faster (M = 770.79; SD = 62.68) than power responses (M = 804.01; SD = 81.03). In mapping condition two the opposite pattern could be observed. Power responses were executed faster (M = 804.11 ms; SD = 70.98) than precision responses (M = 820.69 ms; SD = 67.99). Considered that even in the present experiment in mapping condition one participants had to respond to natural objects with a precision grip, whereas, in mapping condition two they had to respond to natural objects with a power grip, again these data indicate overall faster response times to naturally formed objects.

No other interactions or main effects were found to be significant.

Error Data

The pattern resulted from the analysis applied to mean percentage error rates was similar to that observed in response time data. Again, a significant two-way interaction between Graspability and Response [F (1,22) = 5.008; p = .036; η_p^2 = .185] was found (see Fig. 2.13 below).

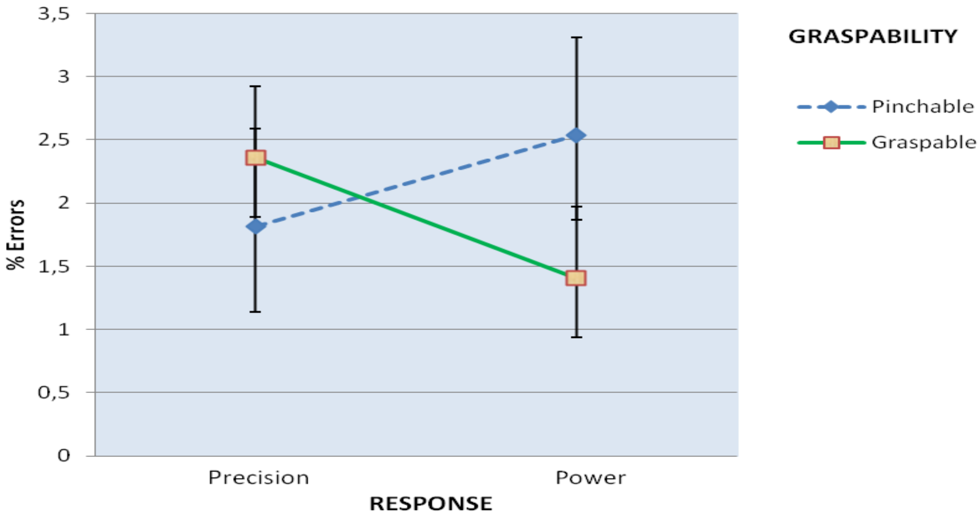


Figure 2.13

Mean Percentage of Errors for Power and Precision Responses to Graspable and Pinchable Objects. Error bars denote standard errors.

S-N-K post hoc analyses showed that participants responded more accurately to graspable objects with a power response (M = 1.40%; SD = 2.27) than with a precision response (M = 2.35%; SD = 2.71). Similarly, pinchable objects tended to be responded to more accurately with a precision response (M = 1.81%; SD = 3.77) than with a power response (M = 2.53%; SD = 3.21), although not significantly.

No other interactions or main effects were found to be significant.

2.4.4 Discussion

As expected, the pattern of results emerged in experiment 3 parallels that observed in the previous experiments. Again, significant interactions were found between Graspability and Response in both the response time data and in error data. This contributes to confirm the hypothesis that object representations and the associated action-related information can be activated independently from the mode of access to object representations, provided that objects are properly identified (Tucker and Ellis, 2004).

As a further test of this hypothesis, two general analyses were run to statistically compare the compatibility effects arisen in experiments 1, 2, and 3. Before moving on to the general discussion, section five of this chapter describes the results of such analyses carried out on both the response time data and error data from all the three experiments.

2.5 General Analyses

Comparison between experiments 1, 2, and 3

In an effort to establish whether the format (or sensory modality) through which objects were presented had had an impact on the compatibility effects observed, two general analyses were run on both the response time data and error data from the three experiments described so far. Participants responses (both mean Rts and mean percentage error rates) were entered into three way mixed analyses of variance with Graspability (pinchable, graspable), Response (precision, power) as within participants factors, and Presentation Mode (object pictures, object written names, object spoken names) as a between participants factor.

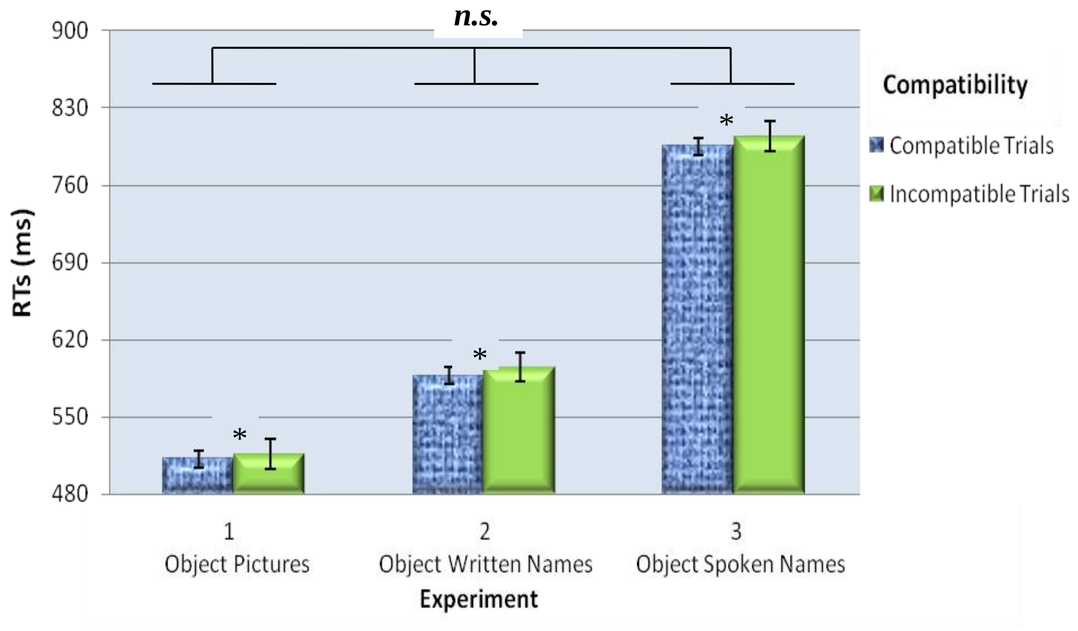
The results showed a significant main effect of Presentation Mode in the response time data with participants categorizing object pictures (M = 514.56; Se = 10.23) 77 ms faster than object written names (M = 591.67; Se = 10.69), and 285 ms faster than object spoken names (M = 799.90; Se = 10.23) [F (2,67) = 207.213; p = .000 η_P^2 = .861].

This difference was not observed in the error data [F (2,67) = 1.081; p = .345]

Averaged over the experiments, the Graspability by Response compatibility effect (i.e., the two-way interaction between Graspability and Response) was highly significant for both measures of performance. Compared to incompatible trials, Rts for compatible trials were on average 7.054 ms faster (4.42 ms in experiment 1, 7.92 ms in experiment 2, and 8.81 ms in experiment 3) [F (1,67) = 25.076; p = .000 η_P^2 = .272], and produced 1.57% fewer errors (1.31% in experiment 1, 1.72% in experiment 2, and 1.67% in experiment 3) [F(1,67) = 17.873; p = .000 η_P^2 = .211].

Of most relevance, however, no three way interaction between Graspability, Response and Presentation Mode factors was observed: the compatibility effect obtained did not differ significantly between the three experiments for both Rts [F (2,67) = .929; p = .400], and Errors [F (2,67) = .121; p = .886]. The detailed pattern of results is shown in Figure 2.14.

In addition, the compatibility effects emerged seem to display a similar temporal evolution, as confirmed by a bin analysis carried out to compare the time course of the effects observed in experiments 1, 2, and 3 (see appendix G).



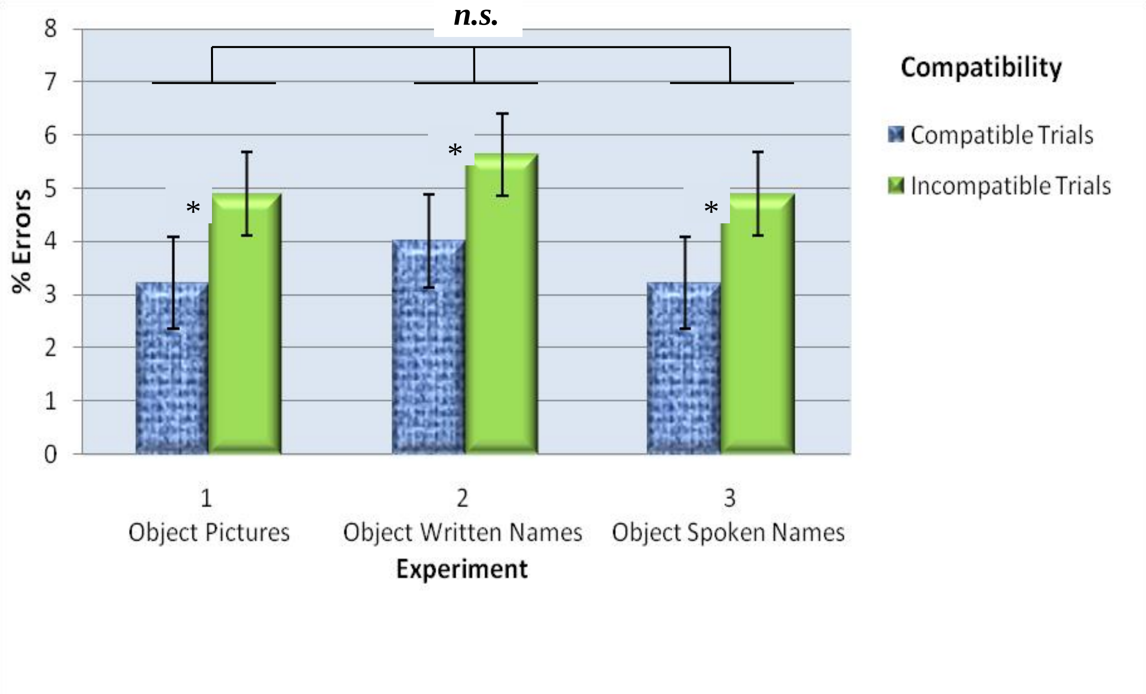


Fig. 2.14

Mean Response Times (top) and Mean Percentages of Errors (bottom) for Compatible and Incompatible Trials in Experiments 1, 2, and 3.
Error bars denote standard errors.

The present analyses confirmed that the three experiments produced similar and statistically indistinguishable results. All of the results from the analyses by subjects were confirmed by separate analyses by items (see Appendix H for more details). This suggests that the compatibility effects arisen from the power and precision components of the grasping action behave independently from the format or sensory modality through which the affording objects are presented. This in turn would suggest that a common neural substrate might be active and responsible for the expression of affordance related effects, regardless of whether objects are represented by pictures or words. This issue will be discussed again in the next section.

2.6 General Discussion

In experiment 1 of this chapter further evidence has been provided for the presence of compatibility effects between the power and precision components of a grasping action and the compatibility of a seen object for grasping by a power or a precision grip. The emergence of grasp compatibility effects even in this experiment, where objects were displayed with no visual information about their size, suggests that the generation and the expression of such effects might depend more on stored semantic knowledge of the objects and their associated actions than on the processing of their on-line visual properties.

In line with this hypothesis, the results of experiments 2 and 3 showed that the potentiation of the actions associated with these components can occur not only during the categorization of visual objects, but even during the language processing of their names where no immediate action-related visual information is available. It would seem that objects can activate their representations, and the action knowledge these contain, as soon as they are identified either visually or through their verbal labels. This implies that the activation of a compatible motor response does not necessarily depend on the visual presence of an object, thus on the on-line visuomotor processing associated with the activity of the dorsal system. Instead, the data argue strongly in favour of an involvement of the ventral system which, as reported earlier, contains object semantic knowledge and is mainly responsible for object recognition.

As discussed in chapter 1, the specialisation of the dorsal system is the on-line control of an ongoing action. During prehension, the activity of the dorsal system is involved when detailed and constantly updated spatio-temporal instructions are required to direct, for example, the hand and the fingers to appropriate locations on an object's surface. In other words, the dorsal system is implicated in the visual monitoring of more extrinsic (or viewpoint dependent) object properties, such as location and orientation, that have to be necessarily computed on-line as this information is subject to continuous variation as the agent or the action target move. On the contrary, more intrinsic properties, such as object size, pertain to permanent characteristics of an object that are constant and independent from specific visual contexts. This kind of information is part of the stored knowledge of the object built up from a history of past interactions that have become integrated with the object representation. Therefore, for example, individuals know that a coin is small and requires a particular type of grip (i.e., between thumb and index finger) independently from contextual factors. So, whilst the precise guidance of thumb and index finger during prehension will rely more and more on the specialized control circuits within the dorsal stream, object knowledge would allow information about the type of grip to be available before a precise on-line dorsal grasp adjustment takes place.

For a property like object size there are thus at least two routes to the activation of its affordance for a particular grasp. An on-line route based on immediate visual attributes of the viewed object, and a semantic route based on the stored knowledge of the object (e.g., Tucker and Ellis, 2004). The data provided in this chapter suggest that either route (visual or lexical) to an object representation is sufficient to activate its grasp affordances. Thus, within an experimental set-up where on-line reaching and grasping are not actually occurring, the generation of grasp compatibility effects depends more likely upon stored semantic knowledge of the object and its associated actions than upon the detailed monitoring and processing of its visual features. This finding is in line with Glover's (2004) dorsal-ventral distinction and its relation with the control-planning systems: the systems involved in motor planning would play a more important role in determining affordance effects that do not depend critically on accurate on-line adjustment and parameterisation.

Overall, the present experiments additionally demonstrate that objects and their names are almost indistinguishable in their ability to evoke and potentiate object-related motor programs. Indeed, no statistical differences were observed between the grasp compatibility effect obtained from the pictures of precision or power compatible objects (experiment 1) and that obtained from both the written and spoken names of those same objects (experiment 2 and 3 respectively). The data provided in this chapter are in line with a series of neuroimaging studies that have revealed considerable overlap in the neural circuitry supporting perceiving, acting on, and knowing about objects (for a review, see Martin, 2007). This finding contributes to support the embodied theories of cognition which propose that object concepts are deeply grounded in perception and action. As discussed in chapter 1, they consist of the re-enactment of past sensorimotor experiences with their concrete referents (Barsalou, 1999; Harnad, 1990; Thelen and Smith, 1994). Within this view, the activation of object concepts leads to a re-experiencing (i.e., a simulation) of the interaction with those objects, and such simulations in turn support the actual interaction with them. As demonstrated in this chapter, this mechanism also occurs in the case of object names, that is when object concepts are expressed in a linguistic format.

In summary, the data from the present experiments showed that the grasp compatibility effect obtained from the names (visually or acoustically presented) of precision or power compatible objects was statistically indistinguishable from that obtained from the pictures of those same objects. This provides further evidence that on-line visual processing of an object is not necessary to produce affordance-based compatibility effects which, in contrast, seem to rely more on the stored semantic knowledge of the object and its associated actions. Such action-related information seems to be automatically accessed and activated as soon as the objects are identified, independently from the mode of access to their representations.

However, if on one hand this interpretation rules out any necessity for visual inputs to be present for micro-affordance effects to be induced, on the other hand the experiments described in this chapter, as well as previous studies that have sought to investigate such effects by using object names, leave open the possibility that visual mental imagery could play a role. Experiment 4, described in the next chapter, was carried out with the specific aim to address this issue.

Chapter Three

3.1 Introduction

In chapter two it has been shown that whether a manipulable object is visible or not has little impact on the micro-affordance compatibility effects produced. Indeed, no significant differences were found between the grasp compatibility effect obtained from the pictures of precision or power compatible objects (experiment 1) and that obtained from both the written and spoken names of those same objects (experiment 2 and 3).

As discussed in the previous chapter, these data suggest that objects do not need to be visually present and processed on-line in order to activate the motor patterns associated with their affordances. It seems that objects can activate their representations, and the action encodings these contain, as soon as they are identified, independently from the format or sensory modality through which objects are presented (seen objects vs. written object names vs. spoken object names).

More importantly, the semantic system, which is supposed to contain knowledge of objects' properties, structure, and functions, was hypothesised to be the main circuit responsible for the generation of micro-affordance effects observed with object names. Specifically, it was suggested that such effects could have arisen as a result of compatibility effects between semantic knowledge about a property of objects (i.e., their size) and the actions that can be carried out on them.

As is apparent, this hypothesis would seem to rule out any necessity for visual inputs to be present for micro-affordance compatibility effects to be induced. Nevertheless, the studies described in this thesis so far, as well as previous studies that have investigated such effects elicited by object names, leave open the possibility that visual mental imagery could play a role. In other terms, this category of studies does not allow to rule out the possibility that participants, while reading or hearing an object name, can form a sort of visual mental image of its referent before giving their responses. In addition, it is worth considering this possibility even in light of the fact that it has been indicated that affordance-based compatibility effects can emerge also in response to imagined objects (Derbyshire, Ellis, and Tucker, 2006).

Experiment 4 described in this chapter was ideated with the specific aim to test this possibility. Experiment 5, instead, was carried out in order to provide further evidence in support of the hypothesis that semantic system could be essential for the expression of micro-affordance based compatibility effects observed with object names.

3.2 Experiment 4

3.2.1 Introduction

The term ‘visual imagery’ refers to the phenomenological experience of seeing with the ‘mind’s eye’. It encompasses the processes of generating, maintaining and manipulating mental images (Kosslyn, 1996).

Baddeley (1986) hypothesised that visual imagery is, together with visual short-term memory, a function of a cognitive system known as ‘visuo-spatial sketchpad’ of working memory. It is described as a modular system designed for short-term retention and processing of visual material, and supervised by the ‘central executive’. A similar (although not completely analogous) system can also be traced in Kosslyn’s (1996) ‘protomodel of the imagery system’, one of the most prominent model to arise in the field of visual mental imagery. According to this model, the topographically organized representations that give rise to the conscious awareness of visual mental imagery are held in a sub-system called ‘visual buffer’.

The reasons for the above brief description of two models of visual mental imagery are two-fold. Firstly, it helps understand that despite several models of visual mental imagery have been proposed over the years, each of them individuates a main component for the retention and processing of visual information. Secondly, and more relevantly to this section, the description provided helps introduce the aim of the present experiment, and explain the reasoning that led to the choice of the methodology employed.

Experiment 4 was devised with the specific aim to test the possibility that visual mental imagery could intervene in the generation of micro-affordance compatibility effects observed with object names. Generally, one of the most powerful way to investigate the contribution of a given cognitive function or capacity of interest is inhibiting it by interfering with the system that is believed to be responsible for it. Since the visuo-spatial sketchpad - or the visual buffer if one takes into account the conceptualization of Kosslyn - is believed to be the system mainly responsible for visual mental imagery, it was decided to interfere with its functioning in order to inhibit participants' capacity to generate and process visual mental images while hearing and categorizing object names.

To this regard, it is worth reporting the work of Quinn and McConnell (1996) who provided evidence that irrelevant visual stimulation selectively interferes with the operation of the visuo-spatial sketchpad, which in turn causes the disruption of visual mental imagery. They asked participants to watch (but ignore) a flickering random array of black and white dots on a screen, termed dynamic visual noise (DVN), while learning a list of words either by verbal processing instructions (i.e., rote rehearsal) or by using a pegword imagery mnemonic. The pegword mnemonic required participants to learn a rhyme in the form 'One is a bun, two is a shoe…', and then learn a list of words by visualising the referent of the first word combined with a bun, that of the second word combined with a shoe, and so forth. At test, recalling the rhyme helped recall of the images, which helped recall of the list words. Performance was typically better with pegword imagery than with rote rehearsal. The authors showed that

DVN only impaired performance in the pegword imagery condition, a robust finding that was replicated in several subsequent studies. They concluded that DVN selectively impairs visuo-spatial working memory by gaining obligatory access to the passive visual store.

The hypothesis that visual material has obligatory access to the visuo-spatial sketchpad had been previously tested by Logie (1986) who reported that irrelevant pictures (e.g., line drawings) gain access to the visuo-spatial sketchpad in a way analogous to the 'irrelevant speech effect' of Salamé and Baddeley (1982). He found that under rote rehearsal, participants' performance was not affected by irrelevant visual material, but the same material disrupted performance with visual mnemonic processing instructions ('irrelevant picture effect'). By contrast, irrelevant speech affected rote rehearsal but had little effect on visual mnemonic processing.

Among the different irrelevant visual stimulation techniques, the DVN technique was chosen for the present experiment for at least two reasons. Firstly, because of its proven robustness and effectiveness in selectively interfering with the visuo-spatial sketchpad, thus in disrupting visual mental imagery. Secondly, it was decided to employ an interfering technique that allowed to use both the same stimuli and task used in the previous experiment with spoken object names. As will be described in the method section, participants were presented with the same stimuli used in experiment 3 and had to perform exactly the same categorization task. This time, however, their gaze had to be kept on a flickering array of black and white dots on the screen (i.e., on the DVN) all the time. In addition, since it has be shown that a very illuminated background on the screen can contribute to attenuate individuals' visual imagery capacity (see Sherwood and Pearson, 2010), it was decided to delimit the DVN with a bright white contour to further decrease the likelihood of participants forming a visual mental image of the objects starting from their names (see figure 3.1 in the method section).

This methodology allowed to interfere selectively with participant's capacity to form and process visual mental images without the necessity of being engaged in an interfering secondary task that could affect participants' performance. Furthermore, given that all conditions remained unchanged across experiments, it provided the possibility to directly compare the performance obtained in this experiment with that obtained in experiment 3.

If no significant differences will be found between the two experiments and similar micro-affordance compatibility effects will continue to show in the present experiment where participants' visual imagery is inhibited, then one should rule out an involvement of this capacity in the generation of such effects observed with object names. In other terms, one could conclude that the effects observed are elicited by simply identifying the objects through their names, without the necessity to create their visual mental reproductions. This conclusion would argue strongly in favour of the hypothesis which assigns to the semantic system a central role in the generation of micro-affordance effects induced by linguistic information about objects.

3.2.2 Method

Participants

Twenty four participants (14 males) aged between 18 and 38 years (Mean Age = 23.54; SD = 4.74) took part in the experiment. They were all native British English speakers and right-handed (Mean Laterality Quotient = 83.85; SD = 15.73) as assessed by a revised version of the Edinburgh Handedness Inventory (Oldfield, 1971; Williams, 1986; see *Appendix B*). Participants had normal or corrected-to-normal vision, and no reading, hearing or motor function impairments were reported. Prior to starting the experiment, informed consent was obtained from all participants who were naïve as to the purpose of the study. Each participant was paid £7 or received University credits for taking part. The study was approved by the Psychology Department Ethical Committee of the

University of Edinburgh and carried out in accordance with the ethical standards of the Declaration of Helsinki (1964).

Materials and Apparatus

The stimulus set and apparatus were the same as those used in experiment 3.

Design and Procedure

The experimental design and procedure employed for the present experiment were the same of those used in experiment 3. Participants were asked to categorize object names into natural or manmade by using the same manipulandum employed in the previous experiments. As in experiment 3, during the practice block a black fixation point at the centre of a white background signalled the start of each trial. Three hundred ms later the digital recording of one of the 92 object names was delivered through a pair of headphones for its own duration. Meanwhile, participants kept their gaze on a black fixation point, which remained in view for 2500 ms or until a response was made. After responding, an inter-trial fixation point appeared for 1000 ms (see figure 3.1, a)

Once they showed a good understanding of the experimental task (i.e., a performance score above 80%) and learned how to hold and use the hand device, the actual experiment started.

Participants were told they would perform the same task. The only difference regarded the fixation point, which was now replaced by a flickering array of black and white dots on the screen (see figure 3.1, b).

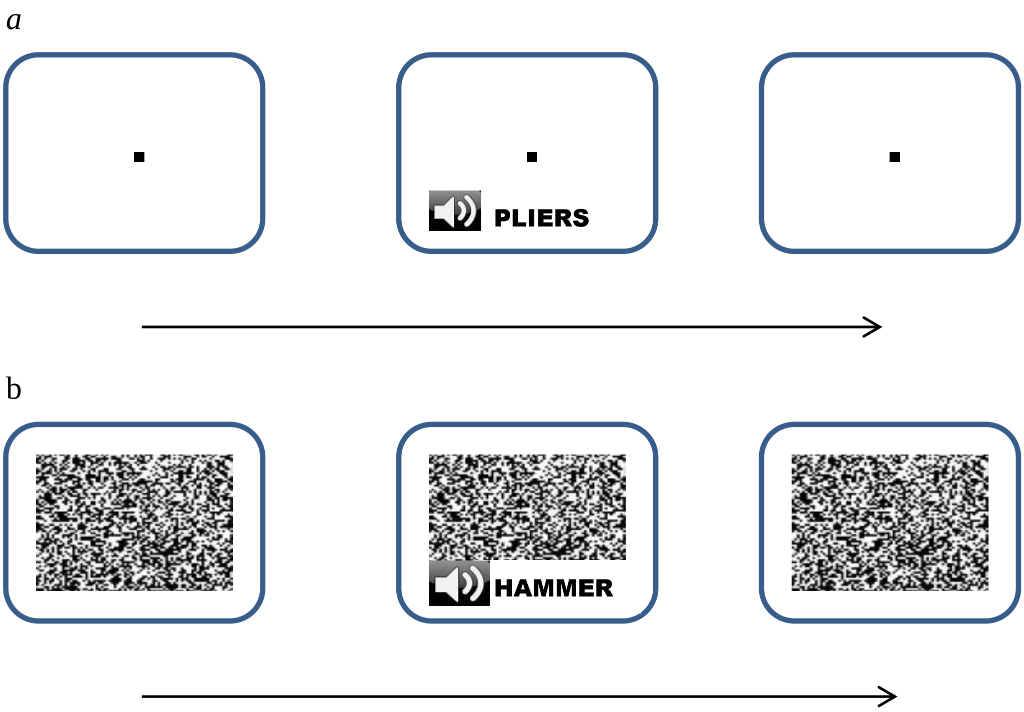


Figure 3.1

a) Sequence of presentation in a typical practice trial.

b) Sequence of presentation in a typical experimental trial.

Once completed the experimental task, all participants were asked to fill in the Vividness of Visual Imagery Questionnaire (VVIQ, see Appendix D) (Marks, 1973) in order to obtain a measure of their visual imagery capacity.

3.2.3 Results

A maximum error rate of 10% was fixed for inclusion for participant data in this study. Based on this criterion, no participant was excluded from the analyses. RTs more than two standard deviations from the participants' means were excluded from the analyses, and mean Rts were calculated using only correct trials. Mean correct Rts and mean percentage error rates were then entered into three-way mixed ANOVAs with Graspability (pinchable, graspable), Response

Type (precision, power) as within participants factors, and Mapping as a between participants factor.

Response Time Data

The analysis for the mean RTs revealed a significant two-way interaction between Graspability and Response [F (1,22) = 7.419; p = .012 η_P^2 = .252]. This interaction is illustrated in Figure 3.2. S-N-K post hoc analyses showed that in the precision response condition responses were executed significantly faster for compatible pinchable objects (M = 774.56 ms; SD = 66.67) than for incompatible graspable objects (M = 785.07 ms; SD = 72.86). Similarly, in the power response condition responses were executed significantly faster for compatible graspable objects (M = 787.32 ms; SD = 64.24) than for incompatible pinchable objects (M = 794.53 ms; SD = 60.66).

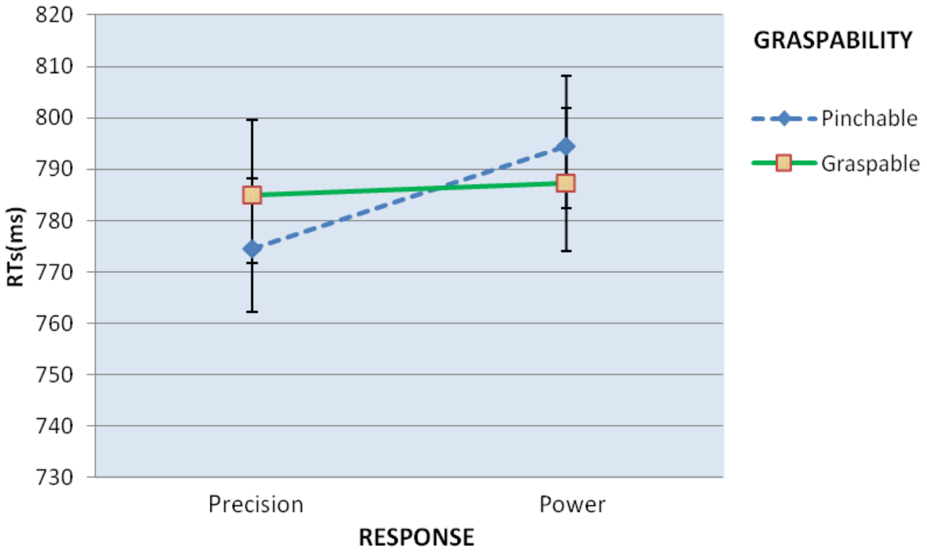


Figure 3.2

Mean Response Times for Power and Precision Responses to Graspable and Pinchable Objects. Error bars denote standard errors.

A significant interaction was also observed between Response and Mapping [F (1,22) = 9.971; p = .005 η_P^2 =.312]. S-N-K post hoc tests revealed that in mapping condition one precision responses were executed faster (M = 762.41 ms; SD = 77.81) than power responses (M = 801.06 ms; SD = 60.29). In mapping condition two the opposite pattern was observed. Power responses were executed faster (M = 780.80 ms; SD = 61.25) than precision responses (M = 797.23 ms; SD = 57.97). A similar pattern of results was reported previously in this thesis, and has been interpreted in terms of overall faster response times to natural objects.

Error Data

The pattern resulted from the analysis applied to mean percentage error rates was similar to that observed in response time data. Again, a significant two-way interaction between Graspability and Response [F (1,22) = 6.737; p = .017 η_P^2 = .234] was found. This interaction is illustrated in Fig. 3.3. S-N-K post hoc tests showed that participants responded significantly more accurately to pinchable objects with a compatible precision response (M = 1.04 %; SD = 1.13) than with an incompatible power response (M = 1.90 %; SD = 1.64). Similarly, graspable objects were responded to more accurately with a compatible power response (M = 1.08 %; SD = 1.39) than with an incompatible precision response (M = 1.67 %; SD = 1.66).

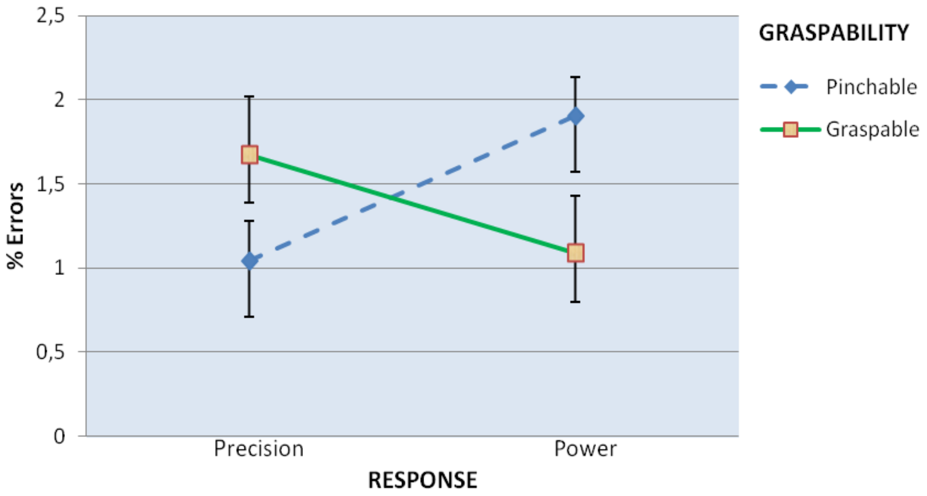


Figure 3.3

Mean Percentages of Errors for Power and Precision Responses to Graspable and Pinchable Objects. Error bars denote standard errors.

No other interactions or main effects were found to be significant.

Across Studies Comparison-Experiments 3 and 4

To determine whether there were statistical differences between the compatibility effects arisen in experiments 3 and 4, further analyses were carried out on both the response time data and error data from the two experiments.

Participants responses were entered into three way mixed ANOVAs with Graspability (pinchable, graspable), Response (precision, power) as within participants factors, and Experiment (experiment 3 and 4) as a between participants factor.

Averaged over both the experiments, the Graspability by Response compatibility effect was highly significant for both measures of performance: compared to incompatible trials, Rts for compatible trials were on average 8.83 ms faster (8.81 ms in experiment 3, and 8.86 ms in experiment 4) [F (1,46) = 15.913; p = .000 η_p^2 = .257], and produced 1.56% fewer errors (1.67% in experiment 3, and 1.44% in experiment 4) [F (1,46) = 11.601; p = .001 η_P^2 = .201].

Of most importance, however, no three way interaction between Graspability, Response and Experiment factors was observed: the compatibility effect obtained did not differ significantly between the two experiments for both Rts [F (1,46) = .000; p = .992], and Errors [F (1,46) = .061; p = .806]. The detailed pattern of results is shown in Figure 3.4.

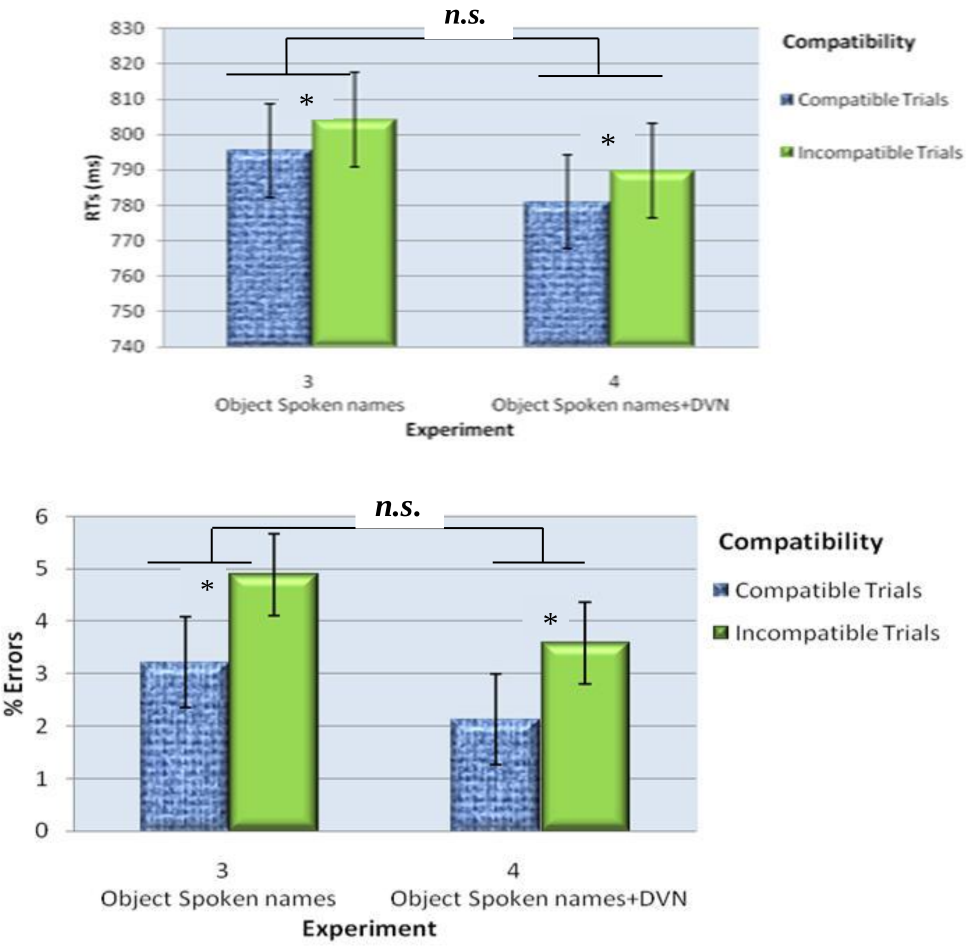


Figure 3.4

Mean Response Times (top) and Mean Percentages of Errors (bottom) for Compatible and Incompatible Trials in Experiments 3 and 4. Error bars denote standard errors.

The present analyses confirmed that experiment 4 with object spoken names and DVN produced a pattern of results similar to that described in the previous chapter for experiment 3. This suggests that interfering with participants' visual processing (i.e., with their visual imagery capacity) in experiment 4 did not have a significant impact on the effects observed.

Furthermore, 21 participants (out of 24) self-reported they were not able to visualize anything while performing their task in experiment 4.

Taken together, the data seem to suggest that affordance-related effects are not mediated by visual imagery, and this points to rule out an involvement of any form of visual processing in the affordance effects observed with objects' names.

Visual Imagery Capacity

To test the possibility that participants' visual imagery capacity might have any impact on the results obtained, further analyses were carried out. Starting from the VVIQ scores obtained, participants were first divided into two categories of visualisers. Participants whose VVIQ scores were above the sample VVIQ mean (M = 35.79; SD = 7.03) were considered 'low visualisers', whereas participants who showed a VVIQ score smaller than the sample VVIQ mean were considered 'high visualisers'. Based on this criterion, eleven low visualisers and thirteen high visualisers were included in the analyses. Mean Rts and mean percentage error rates were then entered into three-way mixed ANOVAs with Graspability (pinchable, graspable), and Response (precision, power) as within participants factors, and VVIQ (high visualisers, low visualisers) as a between participants factor.

The analysis for the mean Rts failed to show either a significant three way interaction between Graspability, Response and VVIQ [F (1,22) = 1.643; p = .213], or a main effect of the VVIQ factor [F (1,22) = .028; p = .869].

Likewise, no three way interactions [F (1,22) = .047; p = .830], or main effects [F (1,22) = .085; p = .773], were found to be significant in the complementary analysis applied to mean percentage error rates.[7]

According to these results, the affordance-related compatibility effects observed with object names seem to behave independently from participants' visual imagery capacity.

3.2.4 Discussion

The results of experiment 4 are consistent with the results of the previously reported experiments which reveal the presence of micro-affordance compatibility effects during language processing of object names. Once again, the results show that power responses to the names that refer to power grip compatible objects are executed faster and more accurately than power responses to the names that refer to precision grip compatible objects, and vice versa.

Experiment 4, however, aimed at testing the possibility that visual mental imagery could mediate the expression of such effects induced by object names. In this respect, the results show that disrupting visual mental imagery by means of the DVN technique does not have any impact on the compatibility effects observed. Indeed, very similar patterns of results were found when comparing the present experiment with experiment 3 where no visual manipulation was employed.

In addition, such effects seemed to behave independently from participants' visual imagery capacity as confirmed by the statistical analysis reported at the

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[7] The same series of analyses was conducted for the previous experiments where object names were used. Consistently with the results obtained in this experiment, neither main effects of the VVIQ factor nor three way interactions were found to be significant. In addition, 21 participants (out of 24) in experiment 2 with object written names, and 20 participants (out of 24) in experiment 3 with object spoken names self-reported they were not visualizing anything while performing their task.

end of the previous section. Also, participants self-reported that they were not able to form any visual mental image while performing their task.

Taken together, the data point to rule out an involvement of any form of visual processing in the affordance effects observed with objects' names. They demonstrate that language processing of words that refer to graspable objects is sufficient to access and activate their representations, which in turn generate compatibility effects related to their grasping affordances. Such a mechanism occurs by simply hearing (or reading) object names, without the need neither to form nor to visually process the visual mental images of their referents.

In addition, as will be discussed later, the results of experiment 4 allow to shed some light on the nature of object representations as well as on the role of the semantic system in the generation of micro-affordance effects induced by object words.

3.3 Experiment 5

3.3.1 Introduction

In the previous experiment, the 'irrelevant visual stimulation' effect of the DVN technique was used to interfere selectively with participants' visual mental imagery in order to test the possibility that this capacity could mediate the expression of micro-affordance compatibility effects observed during language processing of object names.

A similar interfering approach was taken in the present experiment in order to investigate the contribution of the semantic system to the generation of such effects. Specifically, experiment 5 takes advantage of the irrelevant speech effect of Salamé and Baddeley (1982) who demonstrated that unattended and irrelevant speech can selectively interfere with the functioning of the 'articulatory loop' of the working memory. This system includes two components, an active rehearsal process and a passive phonological store (Baddeley, 1990), and seems to be responsible for the processing of verbal material. The irrelevant speech effect was used here with the aim of interfering selectively with verbal processing, which in turn would prevent or limit a full access to the semantic knowledge system. A substantial body of research has shown that background task-irrelevant sounds can be detrimental and interfere with performance on a wide range of cognitive tasks (see Jones, 1995, for an overview). For the most part, research has been restricted to memory tasks that involve seriation or serial recall, namely the process of placing items into order. In this type of paradigm, target items are presented visually and while the memory task is being undertaken irrelevant sound is played. Typically, serial recall is impaired even though participants are asked to ignore what they hear and reassured that they will not be tested on any feature of the sound. However, the disruptive effects of the irrelevant speech have been shown even in more complex cognitive tasks involving comprehension (e.g., Martin, Wogalter, and Forlano, 1988). For example, Martin and collaborators (1988) have shown that performance in reading comprehension tasks can be disrupted by unattended irrelevant speech (see also Oswald, Tremblay, and Jones, 2000). Given that reading demands a greater level of semantic processing than serial recall tasks, the authors interpret their findings as evidence to suggest that the irrelevant speech is able to disrupt the task at two levels, phonological and semantic. They argue that the irrelevant speech, even though ignored, might be processed to some extent semantically, which may tax the semantic system by decreasing the cognitive resources available for the semantic processing of the text (see Oswald, Tremblay, and Jones, 2000, for a similar point of view).

In the present experiment, participants were presented with the same verbal stimuli used in experiment 2 (i.e., object written names) and had to perform exactly the same categorization task. This time, however, while reading and categorizing the object names, they were asked to listen to (but ignore) the digital recording of a reading from a book written in Hebrew.

Having hypothesised a crucial role of the semantic system in the generation of micro-affordance effects elicited by object names, and assuming the effectiveness of the irrelevant speech technique in producing interference with verbal or semantic processing (Quinn and McConnell, 1996; Martin et al., 1988; Oswald et al., 2000), experiment 5 was expected to show a pattern of results different from that emerged in the previous experiments where significant interactions between object graspability and response type were found. Furthermore, we expected to find a significant difference between participants' performance in this experiment and that observed in experiment 2 where no interference with semantic processing was used.

3.3.2 Method

Participants

Twenty four new participants (15 females) aged between 19 and 43 years (Mean Age = 23.5; SD = 5.29) took part in the experiment. They were all native British English speakers and right-handed (Mean Laterality Quotient = 95; SD = 15.81) as assessed by a revised version of the Edinburgh Handedness Inventory (Oldfield, 1971; Williams, 1986; see *Appendix B*). Participants had normal or corrected-to-normal vision, and no reading, hearing or motor function impairments were reported. Prior to starting the experiment, informed consent was obtained from all participants who were naïve as to the purpose of the study. Each participant was paid £7 or received University credits for taking part. The study was approved by the Psychology Department Ethical Committee of the University of Edinburgh and carried out in accordance with the ethical standards of the Declaration of Helsinki (1964).

Materials and Apparatus

The stimulus set and apparatus were the same as those used in experiment 2.

Design and Procedure

The experimental design and procedure employed for the present experiment were the same of those used in experiment 2. Participants were asked to categorize object written names into natural or manmade by using the same hand device employed in the previous experiments. As illustrated in Fig. 3.5 a, during the practice block, a black fixation point at the centre of a white background signalled the start of each trial. Three hundred ms later it was replaced by the target object's name (in the same color on the same background), which remained in view for 2500 ms or until a response was made. After responding, the object's name disappeared and was replaced by an inter-trial fixation point for 1000 ms. A blank white screen for 300 ms acted as a preparatory signal for the following trial. Once they showed a good understanding of the experimental task, the experiment started. Participants were told they would perform the same task. This time, however, they had to perform the task while listening to the digital recording of a reading from the book 'From here and there' by Yosef Haim Brenner, which was written and read in Hebrew. Participants were encouraged to focus on the experimental task, and to ignore as much as possible the irrelevant speech (IS) presented over headphones (see Figure 3.5, b).

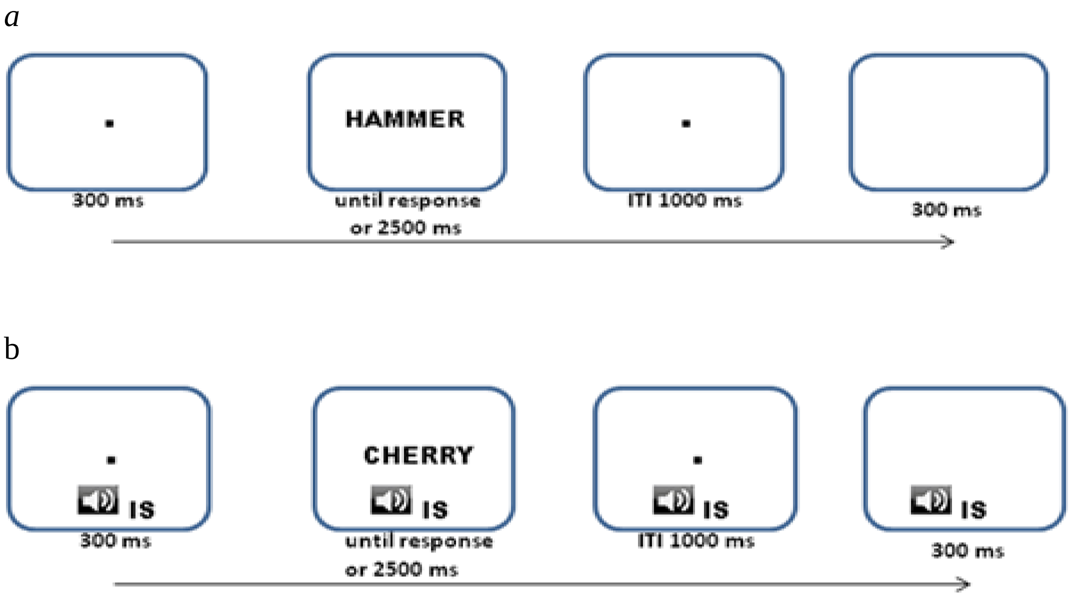


Fig. 3.5

a) Sequence of presentation in a typical practice trial.

b) Sequence of presentation in a typical experimental trial.

3.3.3 Results

A maximum error rate of 10% was fixed for inclusion for participant data in this study. Based on this criterion, no participant was excluded from the analyses. RTs more than two standard deviations from the participants' means were excluded from the analyses, and mean Rts were calculated using only correct trials. Mean correct Rts and mean percentage error rates were then entered into three-way mixed ANOVAs with Graspability (pinchable, graspable), Response Type (precision, power) as within participants factors, and Mapping (1: Natural = Precision Response; Manmade = Power Response/ 2: Natural = Power Response; Manmade = Precision Response) as a between participants factor.

Response Time Data

Congruently to what has often been reported in the literature (see, for instance, Tucker and Ellis, 2001; Derbyshire et al., 2006; Borghi and Riggio, 2009), a main effect of Graspability was observed [F (1,22) = 5.292; p = .031; η_P^2 = .194] in the analysis for the mean RTs. It seems that, overall, responses to graspable objects were executed faster (M = 606.45 ms; SD = 50.90) than responses to pinchable objects (M = 611.09 ms; SD = 52.96). On the contrary, the main effect of Response was not significant [F (1,22) = .815; p = .376].

A significant interaction was also observed between Response and Mapping [F (1,22) = 21.518; p = .000; η_P^2 = .494]. S-N-K post hoc tests revealed that in mapping condition one precision responses were executed faster (M = 616.29 ms; SD = 47.13) than power responses (M = 640.59 ms; SD = 46.68). In mapping condition two the opposite pattern was observed. Power responses were executed faster (M = 571.07 ms; SD = 47.59) than precision responses (M = 607.12 ms; SD = 61.35). As in the previous experiments, this interaction can be interpreted in terms of overall faster response times to natural objects if it is considered that in mapping condition one natural objects were responded to with a precision grip, and in mapping condition two with a power grip.

Most importantly, however, and contrary to what was observed in experiment 2 where no interference with semantic processing was used, in this experiment the analysis failed to show a significant two-way interaction between Graspability and Response [F (1,22) = .115; p = .738] (see figure 3.6). Since p-values do not provide evidence in favour of the null hypothesis, Bayesian information criteria (BIC; see Masson, 2011; Wagenmakers, 2007) were calculated for this interaction. The posterior probability favouring the null hypothesis was p_{BIC} $(H_o|D) = .87$ for the two-way interaction. Given that BIC values between .75 and .95 are considered positive evidence for a hypothesis (Masson, 2011; Wagenmakers, 2007), there is positive evidence for the null hypothesis that Graspability and Response do not interact. It seems that the irrelevant speech technique was effective in interfering with semantic processing, and that such interference in turn resulted in a significant decrease of micro-affordance compatibility effects. This result provides evidence in support of the hypothesis that the semantic system could be the system mainly responsible for the generation and the expression of such effects induced by object names.

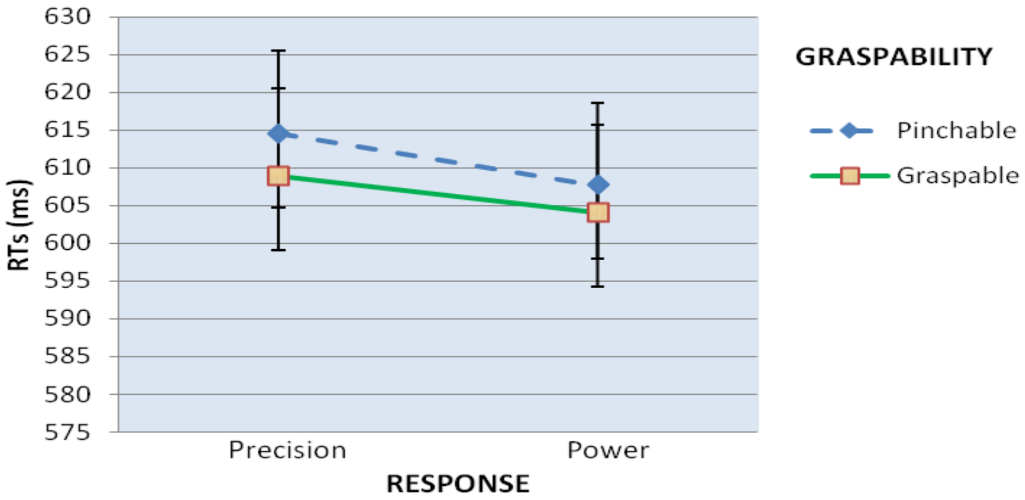


Figure 3.6

Mean Response Times for Power and Precision Responses to Graspable and Pinchable Objects. Error bars denote standard errors.

Error Data

The pattern resulted from the analysis applied to mean percentage error rates was similar to that observed in response time data. The interaction between Response and Mapping was still significant [F (1,22) = 14.434; p = .001; η_P^2 = .396]. S-N-K post hoc tests revealed that in mapping condition one (Natural = Precision Response; Manmade = Power Response) participants made significantly more errors in the precision response condition (M = 3.39 %; SD = 2.30) than in the power response condition (M = 1.35%; SD = 1.43). In mapping condition two (Natural = Power Response; Manmade = Precision Response) the percentage of errors in the power response condition (M = 3.93 %; SD = 2.57) was higher than that observed in the precision response condition (M = 2.67 %; SD = 2.50). This pattern of results could be interpreted as a consequence of a speed-accuracy trade off: the emergence of a higher percentage of errors in response to natural objects was probably due to the fact that participants tended to respond faster to this kind of objects.

The main effect of Response was found to be not significant [F (1,22) = .779; p = .387], as well as the main effect of Graspability [F (1,22) = 1.440; p = .243].

Of most importance, however, again no significant two-way interaction between Graspability and Response [F (1,22) = .047; p = .831] was found. The complementary Bayesian analysis applied to mean percentage error rates provided positive evidence for the absence of this interaction [p_{BIC} (H_o|D) = .88]. The results are shown in figure 3.7.

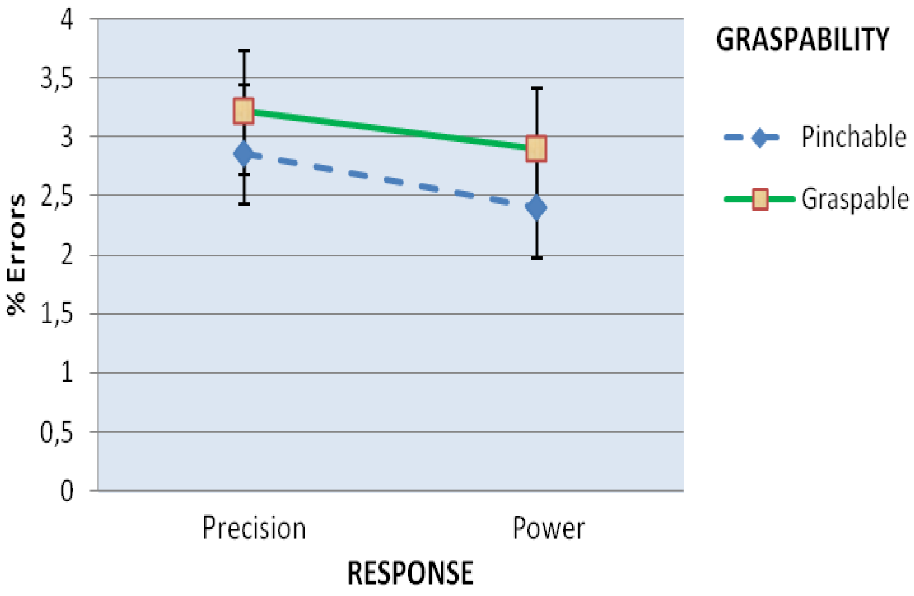


Figure 3.7

Mean Percentages of Errors for Power and Precision Responses to Graspable and Pinchable Objects. Error bars denote standard errors.

Consistently with what observed in RTs data, a significant decrease of affordance-related compatibility effects was found even in this measure of performance. Once again, these data argue in favour of the hypothesis which assigns to the semantic system a necessary role in the elicitation of affordance effects observed with object names.

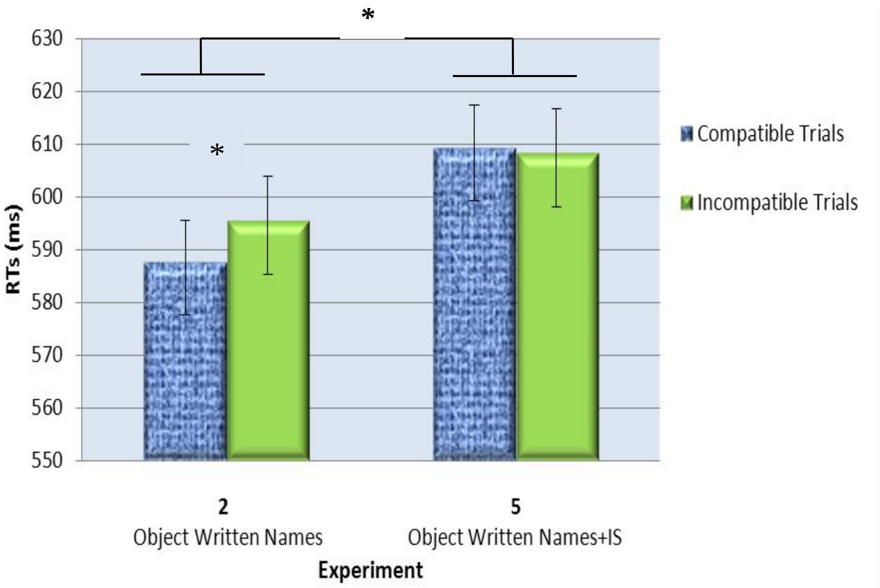
Across Studies Comparison-Experiments 2 and 5

As expected, experiment 5 seems to show a pattern of results different from that observed in experiment 2 where no interference with semantic processing was employed. To determine whether there were statistical differences between the experiments, two additional analyses were carried out on both the response time data and error data from the two experiments.

Participants responses were entered into three way mixed ANOVAs with Graspability (pinchable, graspable), Response (precision, power) as within participants factors, and Experiment (experiment 2 and 5) as a between participants factor.

Averaged over both the experiments, the Graspability by Response compatibility effect failed to reach significance in both Rts [F (1,44) = 3.625; p = .063], and Errors [F (1,44) = 2.969; p = .092].

Of most importance, however, a three way interaction between Graspability, Response and Experiment factors was observed in both Rts [F (1,44) = 6.034; p = .018 η_P^2 = .121], and Errors [F (1,44) = 4.067; p = .050 η_P^2 = .085] (see Figure 3.8).



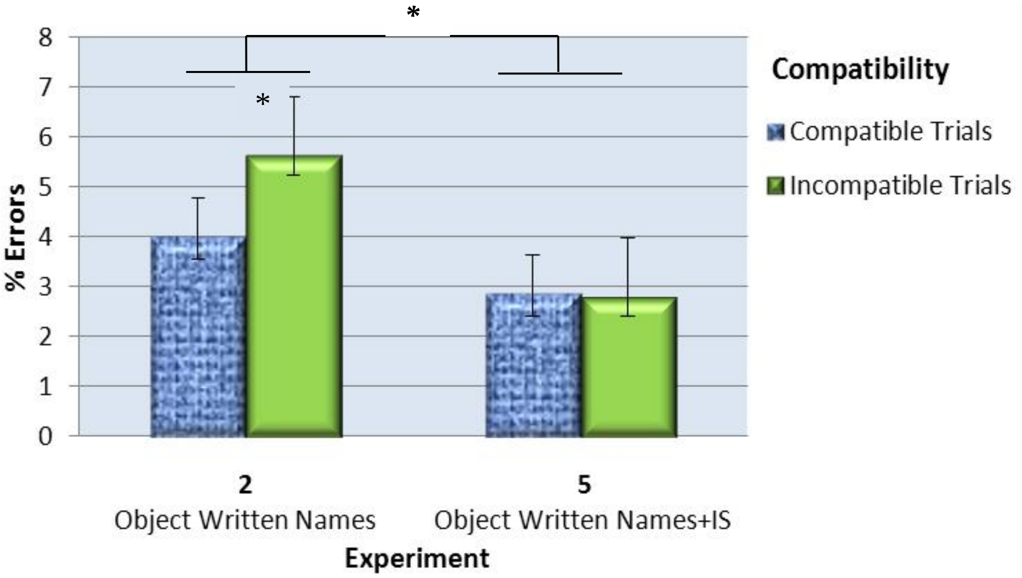


Figure 3.8

Mean Response Times (top) and Mean Percentages of Errors (bottom) for Compatible and Incompatible Trials in Experiments 2 and 5. Error bars denote standard errors.

The interaction with the Experiment factor confirms that experiment 2 and experiment 5 produced different results (see the individual ANOVAs for more details). In particular, it seems that when an interfering technique is used to tax semantic processing – as in experiment 5 – the Graspability by Response compatibility effect tends to disappear or reduce, which suggests that its generation and expression might depend mainly on the intact functioning of the semantic system.

3.3.4 Discussion

The results of experiment 5 indicate that interfering with verbal processing led to a significant decrease of the compatibility effects usually observed with object names and reported in the previous experiments. Such a decrease was evident in both measures of performance. They suggest that the irrelevant speech employed was effective in interfering with the functioning of verbal working memory, which in turn might have decreased the availability of the cognitive resources necessary for a deeper semantic processing of the object names and prevented access to object action knowledge whose activation is responsible of the emergence of affordance based compatibility effects[8].

These data provide additional evidence in favour of the theories that consider cognition as intimately connected to the motor system. Specifically, they show that motor affordances seem to be involved in higher cognitive functions such as verbal working memory and semantic or conceptual knowledge system. Several behavioural studies have shown an involvement of motor affordances and a recruitment of the motor system in working memory tasks (e.g., Smyth, Pearson, and Pendleton, 1988; Smyth and Pendleton, 1989; Woodin and Heil, 1996). For

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[8] It has to be said, however, that the interference used seemed to prevent access to object knowledge, but not completely as confirmed by the fact that participants were still able to access information regarding objects' type and to correctly categorize them as natural or manufactured.

example, Derbyshire, Ellis, and Tucker (2006) presented participants with a series of pictures of objects that could have significance for the action of either pinching (i.e., between thumb and index finger) or grasping (i.e., whole-hand grip). As in the experiments described so far in this thesis, participants were asked to categorize objects into natural or manmade by making precision- and power-grip compatible responses. The results showed the presence of grasp compatibility effects even when objects had to be remembered, namely when participants made an action response to objects 700 ms after they were removed from view. A role of the motor system in working memory has also been suggested by studies that revealed activation of the premotor cortex during visual working memory tasks (e.g., Haxby et al., 1994; Owen, Evans, and Petrides, 1996; Owen et al., 1999; Smith, 2000). In a fMRI study by Mecklinger et al. (2004), for example, activation of premotor cortex during a working memory task was observed for manipulable but not for non-manipulable objects. Since manipulable objects have affordances, whereas non-manipulable objects do not, these results suggest that affordances are recruited for working memory. Nevertheless, the results of other studies do not seem to suggest an involvement or a role of motor affordances in visual working memory performance (e.g., Pecher, 2012; Pecher, Klerk, Klever, Post, van Reenen, and Vonk, 2013). Pecher and collaborators (2013), for instance, investigated the effect of motor interference on an N-back working memory task in which a series of items were presented. Items could be pictures of either familiar manipulable and non-manipulable objects (experiment 1) or novel objects (i.e. unfamiliar spheres) that looked manipulable or not manipulable (experiment 2). Participants had to indicate whether an item was repeated at a distance of N trials. In order to interfere with motor plans for gasping and manipulating objects, participants were asked to make a fist with both hands and then stretch their fingers one by one but simultaneously for both hands. The results showed that in neither experiment did the concurrent motor interfering task affect memory differently for manipulable and non-manipulable objects. The authors interpret these results as evidence to suggest that motor affordances do not support visual working memory. They argue that if motor affordances had played a role in working memory, performance for manipulable objects would have been affected more by motor interference than performance for non-manipulable objects. One plausible explanation for the contrasting results reported here could lie in the type or degree of elaboration required to perform the different cognitive tasks. It is possible to hypothesise that object motor affordances are involved more in those circumstances and tasks that require explicit action knowledge and a deeper semantic or conceptual processing. Indeed, in tasks that require participants to access more to object conceptual knowledge – as in semantic categorization tasks – a clear recruitment of the motor system can be observed.

In conclusion, the present data provide additional evidence for a close relationship between cognition and motor system. More specifically, they suggest that the semantic system and its intact functioning might be essential for the generation and expression of micro-affordance effects. They further suggest, together with the results of experiment 4, that object representations activated during language processing of object names might be more semantic or ‘propositional’ than depictive in nature, therefore more related to stored semantic knowledge of the object and its associated actions than to its detailed visual properties. The theoretical implications of this interpretation and its relationship with the different views of conceptual representation will be addressed in chapter 5.

3.4 General Discussion

In the previous chapter further evidence has been presented to suggest that objects do not need to be visually present and processed on-line in order to activate and potentiate the motor patterns associated with their affordances. It has been shown that object names are able to potentiate actions arising from the power and precision component of the grasping action in a way similar to that observed with real objects or object pictures.

The experiments reported in this chapter, instead, provide evidence suggesting that visual mental imagery does not seem to be involved in this mechanism which seems, rather, mediated by the semantic knowledge system.

Specifically, in experiment 4 it has been shown that micro-affordance compatibility effects did emerge during language processing of object names even following disruption of visual processing. On the contrary, in experiment 5 no significant compatibility effects were observed following disruption of semantic processing.

As already reported, these findings point to rule out the involvement of any form of visual processing in the affordance effects observed with object names. They demonstrate that language processing of words that refer to manipulable common objects is sufficient to activate their representations, which in turn generate compatibility effects related to their grasp affordances. Such a mechanism, therefore, seems to occur by simply accessing objects' semantic knowledge (from their written or spoken names) without the need neither to form nor to visually process the visual mental images of their referents.

The present findings also allow to shed some light on the nature of object representations. According to the view outlined, object representations activated during language processing of object names seem to be semantic (or declarative) rather than pictorial, therefore more related to stored semantic knowledge of the object and its associated actions than to its detailed visual features.

Overall, the evidence provided in this chapter contribute to support all the information-processing models of action which emphasise the role of stored semantic knowledge in determining which action is selected as a response to objects (see, for example, MacKay, 1985, 1987; Roy and Square, 1985; Creem and Proffit, 2001). In addition, it is consistent with the model of action selection proposed by Rumiati and Humphreys (1998), which includes two separate information-processing routes to action, a direct visual route responsible for the selection of actions to be performed in response to seen (or visual) objects, and a semantic route that mediates the selection of actions to be performed in response to object names (see figure 3.9).

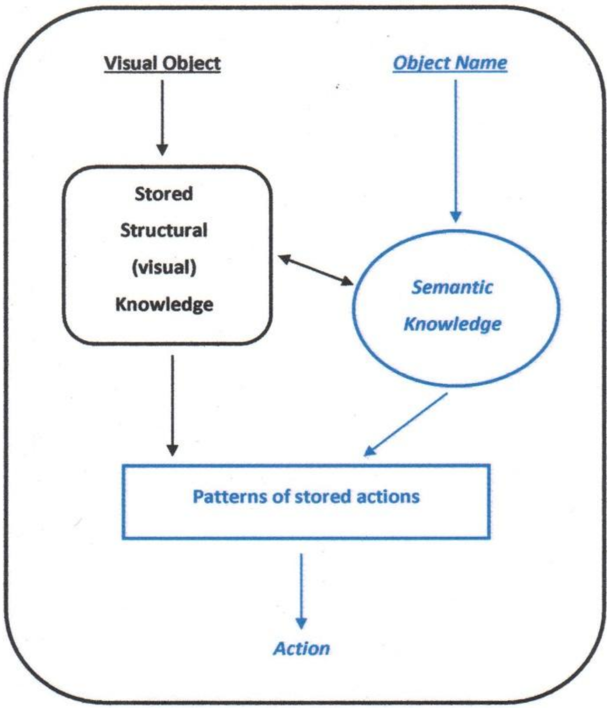

Figure 3.9

Rumiati and Humphrey's Model of Action Selection.

It has to be noted, however, that the experiments described in this thesis only investigate the power and precision component of the grasping action, which is related to a specific property of objects, namely their size.

Thus, the present conclusions can only be applied and generalized to the intrinsic properties of an object which are hypothesised to be stored permanently as integral components of the object off-line representation and, as discussed in chapter one, are related to the emergence of stable affordances.

The idea that object size is an object property that can be semantically represented and accessed through object names without recourse to visual inputs is also supported by Kosslyn (1996) who suggests, even though within his conceptualisation of the visual mental imagery system, that object size is encoded in associative memory together with other different properties of an object.

This finding, together with the fact that micro-affordance compatibility effects are observed also with object names and are mediated solely by a semantic route, has implications for the neural bases of such effects as it allows to reconsider the role of the ventral and dorsal neural pathways.

Based on the evidence presented, the ventral system, which is thought to contain long-term conceptual knowledge and to be responsible for object recognition, can be considered as the main neural substrate for the expression of micro-affordance effects induced by object words. On the contrary, the dorsal system would be activated only in those situations that require the visual processing of more extrinsic and variable properties of objects (for example, object orientation) which requires, in turn, an on-line and context-specific visuomotor coordination.

However, it is also possible to take into account the more recently proposed ‘dorsal-only hypothesis’ according to which the dorsal system would include two distinct routes, a pure dorso-dorsal route involved in on-line visuomotor control, and a dorso-ventral route that includes semantic representations of objects and would encode the most common ways with which individuals interact with them (e.g., canonical affordances) (Gentilucci, 2003).

It has been suggested that stable affordances are represented more ventrally, whereas variable affordances are represented more dorsally. Specifically, it seems that the more extrinsic properties of objects (or variable affordances) would activate predominantly the dorso-dorsal route, whilst the intrinsic properties of objects (or stable affordances) would activate primarily the dorso-ventral route of the dorsal pathway (Rizzolatti, Matelli, 2003; Sakreida, Menz, Thill, Rottschy, Eickhoff, Borghi, Ziemke, and Binkofski, 2013).

In conclusion, it can be said that the evidence provided in this chapter can be taken as further demonstration of the close relationship that exists between action and cognition.

In this regard, it is worth introducing the concept of ‘action semantics’ proposed very recently by van Elk, van Schie, and Bekkering (2014) to refer to that declarative and procedural knowledge about objects (both functional and manipulation knowledge) which enables individuals to use objects in a purposeful and effective manner. The authors prefer using the term action semantics to alternative terminology (for instance, conceptual knowledge, object knowledge, action-oriented representations, etc.) mainly to emphasise the fact that action and semantics are strongly interlinked (Rueschemeyer, Lindemann, van Elk, and Bekkering, 2009). They argue that action planning and object use do not only involve low-level processes of motor control, but also depend on the use of semantic knowledge as demonstrated, for example, by the fact that neurological patients with semantic dementia are often characterised by a general loss of semantic knowledge which leads to the manifestation of selective impairments in their ability to interact with objects in a meaningful way (Patterson, Nestor, and Rogers, 2007; Pobric, Jefferies, and Ralph, 2010).

Semantic processing, in turn, also taps into the resources of the action system as demonstrated, for instance, by the fact that the processing of action related words has been found to be associated with activation of motor related brain areas implicated in the production of the same actions those words refer to (Pulvermuller, 2013).

In addition, the term action semantics does not only involve knowledge about the use of objects, but also encompasses the interactions between action and language as shown by a corpus of studies which investigate the bidirectional relation that exists between these two different systems (see, for example, section 1.2 in chapter one).

In the next chapter, two experiments will be presented. They were carried out in an effort to provide information about the time course with which affordance related motor activity develops during language processing of object written names (experiment 6 and 7). Experiment 7, in addition, takes advantage of a

Transcranial Magnetic Stimulation technique to examine whether semantic information about objects, once again accessed through their written names, can be automatically translated into specific motor activity even in the complete absence of any intention or requirement to act.

Chapter Four

4.1 Introduction

Over the years, a consistent number of studies have shown that the manipulation of objects is associated with the activation of a fronto-parietal cortical circuit which reflects visuo-motor transformations that adapt hand shaping to the specific properties of an object. Such activation has been observed both in the brain of non-human primates (see, for example, Rizzolatti, Scandolara, Matelli, and Gentilucci, 1981; Kurata and Tanji, 1986; Rizzolatti et al., 1988; Taira, Mine, Georgopoulos, Murata, and Sakata, 1990; Sakata, Taira, and Murata, 1992; Hepp-Raymond, Husler, Maier, and Qi, 1994) and in the human brain (Binkofski et al., 1999). However, it has been found that the same premotor and parietal areas of this circuit are recruited not only when actually interacting with objects, but even during object perception. For example, a population of neurones located in these regions in the brain of macaque monkeys, and called 'canonical neurones', have been found to fire when manipulable objects are presented (Rizzolatti et al., 1988; Murata et al., 1997). In humans, neuroimaging studies (both functional magnetic resonance imaging, fMRI, and positron emission tomography, PET) have confirmed the activation of such a circuit during object observation (Grèzes and Decety, 2002; Grèzes, Armony, Rowe, and Passingham, 2003; Grèzes, Tucker, Armony, Ellis, and Passingham, 2003; Binkofski, Buccino, Zilles, and Fink, 2004).

This activation would represent the neural counterpart of Gibson's (1979) concept of object affordances - or micro-affordances in Ellis and Tucker's (2000) conceptualization - introduced in chapter one. According to the affordance hypothesis, simply viewing an object can stimulate the human motor cortex into producing specific object-related motor plans. Importantly, such motor plans would be activated automatically, potentiating appropriate motor responses even when there is no intention to implement them.

Several studies from the fields of experimental psychology and neuroscience have provided evidence of such a phenomenon (see, for example, Chao and Martin, 2000; Craighero, Fadiga, Rizzolatti, and Umiltà, 1999; Tucker and Ellis, 1998; Ellis and Tucker, 2000). For example, a number of behavioural works have shown that participants are faster (or more accurate) at making motor responses that are congruent with those that would be appropriate for handling an object they were exposed to (e.g., Tucker and Ellis 2001; Ellis and Tucker, 2000; Ellis, Tucker, Symes, and Vainio, 2007). Experiment 1, described in this thesis, can be included in this branch of research. The study replicates the findings of other studies employing a similar methodology (see, for example, Ellis and Tucker's seminal study, 2000), and contributes to support the notion that objects can automatically generate motor plans independently from an individual's intentions.

Evidence for such motor recruitment from object observation is not limited to behavioural studies or studies employing imaging techniques. More direct evidence comes from studies that make use of Transcranial Magnetic Stimulation (TMS) technique to measure the cortical excitability in motor regions. For instance, Buccino et al. (2009) used a TMS protocol during which right-handed participants passively observed the pictures of common objects that could be presented with either an intact or a broken handle and oriented to the left or to the right. At a very early point (after 200 ms from the stimulus onset), participants received TMS over the left hemisphere hand motor area while motor evoked potentials (MEPs) were registered from a muscle of the hand. The results showed bigger MEPs when participants were exposed to intact-handle objects oriented to the right, compared to the other experimental conditions. Since the size of the MEPs recorded from a specific muscle are known to raise with increasing cortical preparation for relevant motor acts (Izumi et al., 1995; Rosler and Magistris, 2008), this finding can be taken to imply that a right-handed action was being planned to a greater extent in response to right-oriented objects.

Thus far, some evidence has been presented showing that the motor system is responsive to the presentation of objects in physical or pictorial form. But what happens when individuals are exposed to the names of those same objects?

In the previous two chapters, evidence has been provided to support the notion that objects do not need to be visually present and processed on-line in order to activate and potentiate the motor patterns associated with their affordances. Specifically, it has been shown that object names can potentiate actions arising from the power and precision component of the grasping action in a way similar to that observed when their actual referents (both real objects and object pictures) are presented. Furthermore, this motor potentiation seems to occur without the need to recur to visual inputs (e.g., to form objects' visual mental images) and to visually process them. Rather, it has been demonstrated that this mechanism mainly relies on the semantic system which is believed to contain the semantic representations of the intrinsic properties of objects that, once accessed and activated through their names (written or acoustically presented), are able to evoke stable action-relevant object information. This semantic information, in turn, generates and potentiates specific object-related motor programs that are translated, on a behavioural level, into the grasp related compatibility effects observed. In sum, such findings demonstrate that objects and their names are almost indistinguishable in their ability to evoke motor programs. Such similarity is in line with the embodied theories of language perception (Barsalou, 1999; Fisher and Zwaan, 2008; Gallese and Lakoff, 2005; Glenberg, 1997; Lakoff, 1987; Pulvermuller, 2002; Zwaan and Taylor, 2006; Zwaan, 2004), which posit that the processing and the understanding of language are achieved by recruiting the same sensory and motor neural systems activated when individuals experience the actions or objects to which words refer.

It remains unclear, however, whether this semantic, non-visual motor potentiation can be *automatically* translated into specific motor activity, as suggested by the embodied theories of language, even in the absence of any intention or requirement to act. In addition, little is known about the time course with which affordance related motor activity develops during language processing of object names.

Experiments 6 and 7 presented in this chapter were carried out in order to shed some light on these issues.

4.2 Experiment 6

4.2.1 Introduction

As mentioned above, the present study, together with experiment 7, was carried out in order to provide information about the temporal evolution of the motor plans afforded by the names of manipulable objects. To this aim, it was devised a modified version of the experimental design employed in most of the experiments described in this thesis.

Once again participants were exposed to the written names of natural or manmade objects that have also a significance for the action of pinching or grasping. Like in the previous experiments, their task consisted of reading and categorizing them by using a manipulandum able to mimick precision or power grips. This time, however, their response had to be given exclusively when the object name changed its colour from black to green (i.e., when the ‘target response’ was presented). Thus, such a design allowed to introduce two different stimulus-onset asynchronies (SOAs) between the onset of the object name and the presentation of the target response, and examine the response of the motor system to object names at different time points.

As in the previous experiments, a significant interaction between object type (i.e., pinchable, graspable) and response type (i.e., precision, power) was expected to be observed. In particular, it was expected that power grasp responses to the names of objects optimally compatible with a power grasp action would be executed faster and more accurately than power grasp responses to the names of objects optimally compatible with a precision grasp action, and that precision grasp responses to the names of objects optimally compatible with a precision grasp action would be executed faster and more accurately than precision grasp responses to the names of objects optimally compatible with a power grasp action. Furthermore, based on the few studies reported in literature showing that the motor system is modulated by tool nouns at an early time point (see, for example, Gough, Riggio, Chersi, Sato, Fogassi, and Buccino, 2012), more evident micro-affordance compatibility effects were predicted for the early SOA condition compared to the late SOA condition.

4.2.2 Method

Participants

Twenty six participants (17 males) aged between 18 and 30 years (Mean Age = 22.3; SD = 3.22) took part in the experiment. They were all native British English speakers and right-handed (Mean Laterality Quotient = 98.07; SD = 6.45) as assessed by a revised version of the Edinburgh Handedness Inventory (Oldfield, 1971; Williams, 1986; see *Appendix B*). Participants had normal or corrected-to-normal vision, and no reading, hearing or motor function impairments were reported. Prior to starting the experiment, informed consent was obtained from all participants who were naïve as to the purpose of the study. Each participant was paid £7 or received University credits for taking part. The study was approved by the Psychology Department Ethical Committee of the University of Edinburgh and carried out in accordance with the ethical standards of the Declaration of Helsinki (1964).

Materials and Apparatus

The stimulus set and apparatus were the same as those used in experiment 2. This time, however, the written names of just 36 common objects (18 for each category) were presented (see Appendix A for a complete listing of the stimuli used). Each word could comprise one or two syllables, and be formed by 4 up to

7 letters[9]. Overall, the mean syllables number of the object names was 1.77 (SD = .59), whilst the mean letters length was 5.55 (SD = .80). Most importantly, the mean letter length of the power compatible object names (M = 5.72; SD = .66) did not differ from the mean letter length of the precision compatible object names (M = 5.38; SD = .91).

Design and Procedure

The procedure was similar to that used in experiment 2. All participants were presented with written instructions (Appendix C), and completed 12 practice trials before commencement of the main experiment. Once they showed a good understanding of the experimental task (i.e., a performance score above 80%) and learned how to hold and use the hand device, the experiment started. As illustrated in Fig. 4.1, a black fixation point at the centre of a white background signalled the start of each trial.

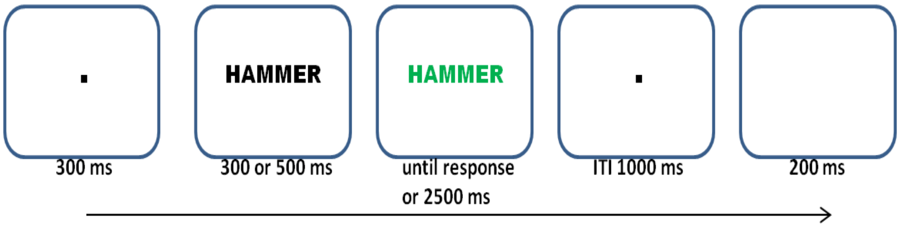

Figure 4.1

Sequence of presentation in a typical experimental trial.

Three hundred ms later it was replaced by an object’s written name (i.e., the ‘prime stimulus’) displayed in black on the same white background. The SOA was varied for each of the primes, so that the time between the prime stimulus onset and the presentation of the response target could be 300 or 500 ms. The

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[9] For the experiments reported in this chapter a reduced number of object names were chosen in order to reduce stimuli variability.

response target, which consisted of a change in the prime's colour from black to green, remained in view for 2500 ms or until a response was made. Participants were instructed to decide whether or not the name referred to a natural or manmade object by making a response on the hand device. Half the participants were instructed to make a precision response for names which referred to natural objects, and to make a power response for names which referred to manmade objects. The opposite mapping rule was used for the other half of the sample. Participants were asked to respond as fast as possible whilst maintaining accuracy. In addition, they were asked to respond exclusively when the object's written name changed its colour from black to green.

After responding, the object's name disappeared and was replaced by an inter-trial fixation point for 1000 ms. A blank white screen for 200 ms acted as a preparatory signal for the following trial.

Overall, there were 216 trials (3 repetitions of each object's name x 18 stimuli per object category x 2 object categories x 2 SOAs) divided into nine blocks of 24 trials. At the end of each block, participants received a feedback on their performance on the screen**.** The order of trial presentation was completely randomized for each participant.

After the experimental session, all participants were debriefed and given a compensation for participating in the study.

4.2.3 Results

A maximum error rate of 10% was fixed for inclusion for participant data in this study. Based on this criterion, two participants were excluded from the analyses. RTs more than two standard deviations from the participants' means were excluded from the analyses, as well as responses given before the prime stimulus changed its colour to green. Thus, mean Rts were calculated using only correct trials.

Mean correct Rts and mean percentage error rates were then entered into four-way mixed ANOVAs with Graspability (pinchable, graspable), Response

Type (precision, power), and SOA (300, 500 ms) as within participants factors, and Mapping (1: Natural = Precision Response; Manmade = Power Response/ 2: Natural = Power Response; Manmade = Precision Response) as a between participants factor.

Response Time Data

The four-way analysis applied to the mean RTs showed a significant main effect of Time [F (1,22) = 435.816; p = .000; η_p^2 = .952]. It seems that, overall, participants tended to respond faster in the 500 ms timing condition (M = 216.53; SD = 41.53) than in the 300 ms timing condition (M = 324.75; SD = 35.21). Consistently with what observed in the previous experiments, the predicted two-way interaction between Graspability and Response was significant [F (1,22) = 6.302; p = .020; η_p^2 = .223]. This interaction is illustrated in Fig. 4.2.

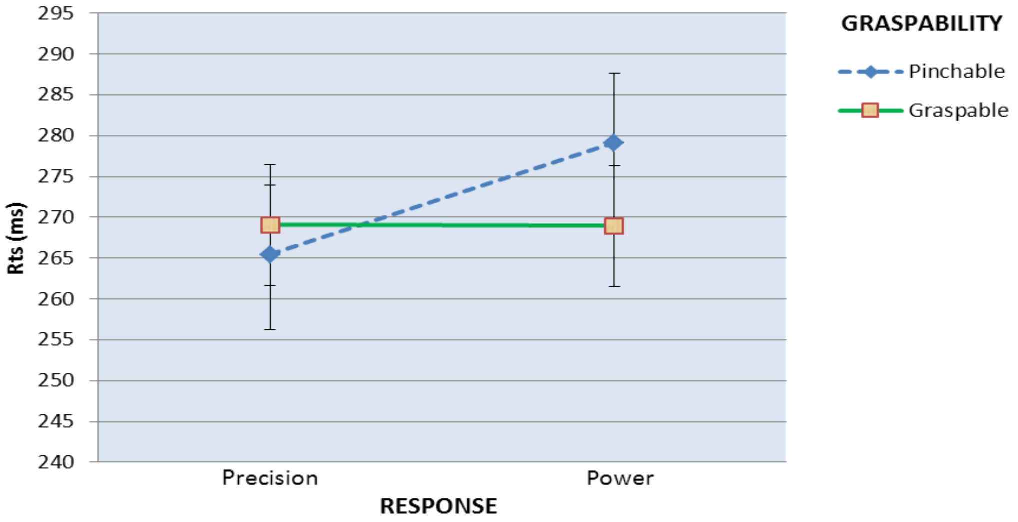


Figure 4.2

Mean Response Times for Power and Precision Responses to Graspable and Pinchable Objects. Error bars denote standard errors.

S-N-K post hoc analyses showed that in the power response condition responses were executed significantly faster for compatible graspable objects (M = 268.92 ms; SD =35.82) than for incompatible pinchable objects (M = 279.12 ms; SD = 44.31). Even though this grasp compatibility effect did not emerge in the precision response condition where responses to pinchable objects (M = 265.44; SD = 41.29) were only slightly faster than responses to graspable objects (M = 269.08; SD = 36.53), it seems that participants responded significantly faster to pinchable objects with a precision response (M = 265.44; SD = 41.29) than with a power response (M = 279.12; SD = 44.31).

On the contrary, the three-way interaction between Graspability, Response, and Time was not significant [F (1,22) =.51; p = .823]. Nevertheless, for completeness and considered that the experiment's focus was on the timing of affordance generation with object names, separate 2 (Graspability) x 2 (Response) x 2 (Mapping) ANOVAs were conducted for each of the two different timing conditions.

A main effect of Graspability was found [F (1,22) = 4.592; p = .043; η_p^2 = .173] in the 300 ms timing condition. Overall, responses to graspable objects were executed faster (M= 321.79 ms; SD=34.27) than responses to pinchable objects (M= 327.72 ms; SD=37.38).

For the same timing condition, the interaction between Graspability and Response was significant [F (1,22) = 5.534; p = .028; η_p^2 = .201].

This interaction is illustrated in Fig. 4.3. S-N-K post hoc tests showed that in the power response condition responses were executed significantly faster for compatible graspable objects (M = 321.93 ms; SD =37.01) than for incompatible pinchable objects (M = 335.42 ms; SD = 46.12). As shown in the general analysis, this grasp compatibility effect did not emerge in the precision response condition where responses to pinchable objects (M = 320.02; SD = 35.9) were only slightly faster than responses to graspable objects (M = 321.65; SD = 39.69). However, participants seemed to respond significantly faster to pinchable objects with a precision response (M = 320.02; SD = 35.9) than with a power response (M = 335.42; SD = 46.1).

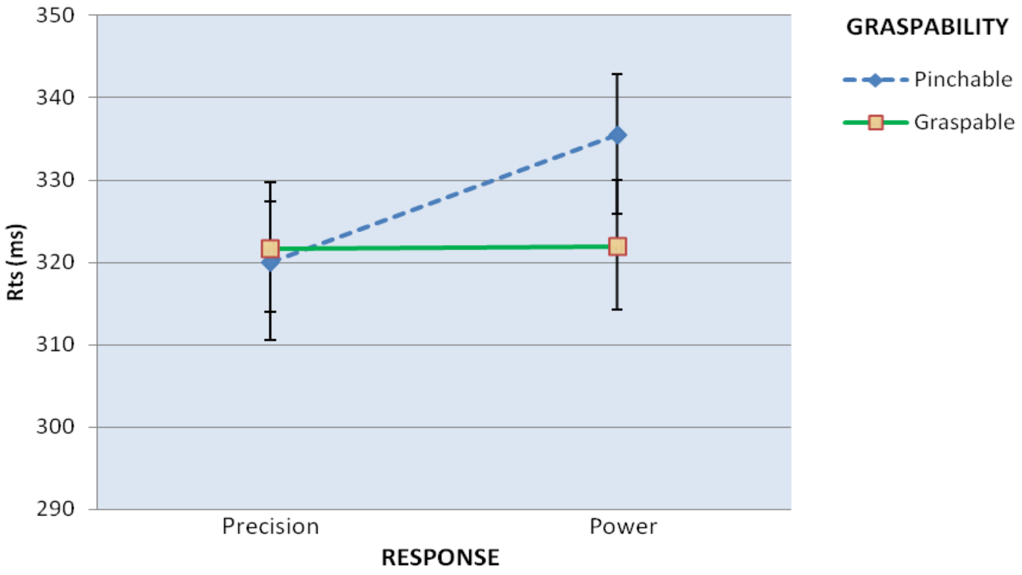


Figure 4.3
Mean Response Times for Power and Precision Responses to Graspable and Pinchable Objects in the 300 ms timing condition. Error bars denote standard errors.

No main effects or interactions were found to be significant for the 500 ms timing condition (see Fig. 4.4).

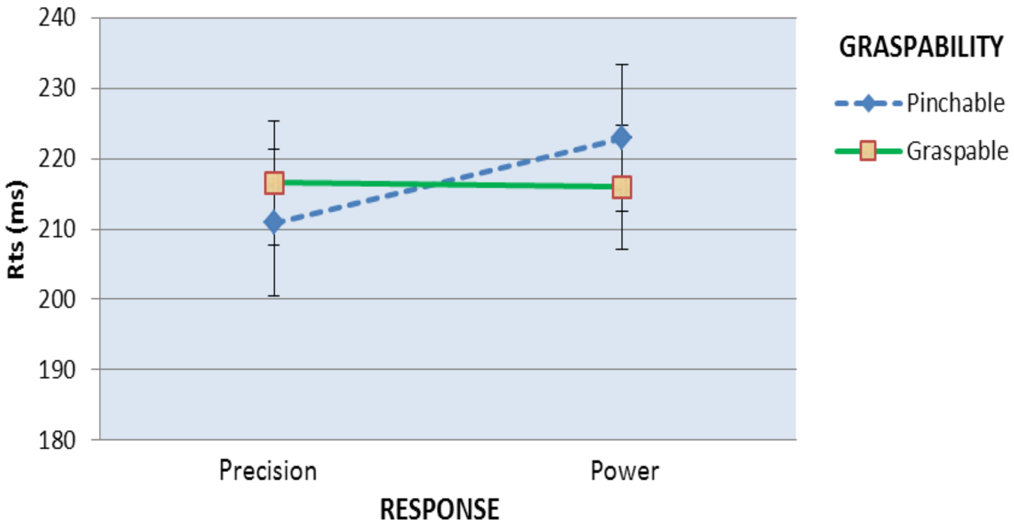


Figure 4.4

Mean Response Times for Power and Precision Responses to Graspable and Pinchable Objects in the 500 ms timing condition. Error bars denote standard errors.

Error Data

Similarly to what observed in response time data, the four-way analysis applied to mean percentage error rates failed to show a three-way interaction between Graspability, Response, and Time [F (1,22) = .141; p = .711].

However, as illustrated in Fig. 4.5, the interaction between Graspability and Response was still significant [F (1,22) = 4.292; p = .050; η_p^2 = .163]. It can be observed that the percentage of errors was higher when graspable objects were responded to with an incompatible precision response (M = 2.75%; SD = 2.64) than with a compatible power response (M = 1.49%; SD = 2.07), and that participants tended to commit more errors when pinchable objects were responded to with an incompatible power response (M = 2.09%; SD = 2.46) than with a compatible precision response (M = 1.94%; SD = 2). However, S-N-K post hoc tests indicated that the latter difference was not significant.

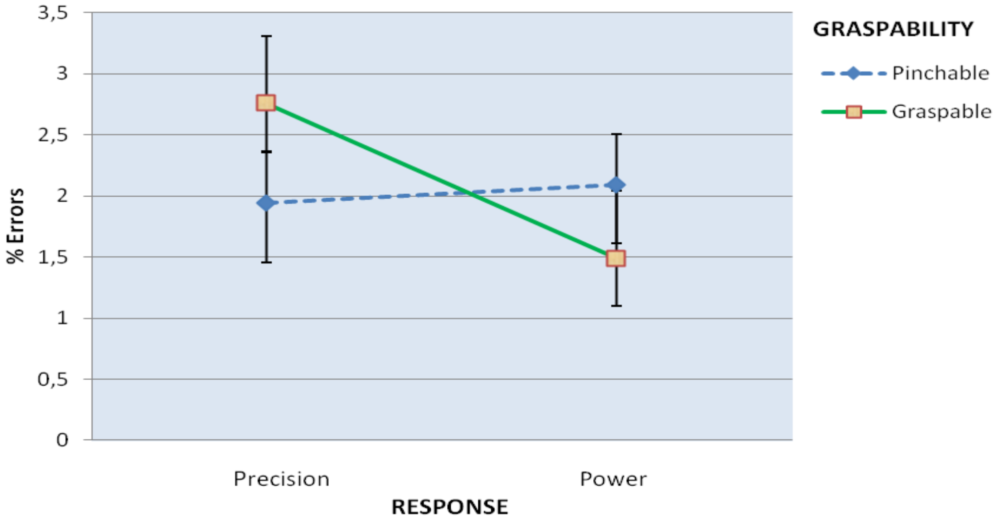


Figure 4.5

Mean Percentages of Errors for Power and Precision Responses to Graspable and Pinchable Objects (data averaged across all time conditions). Error bars denote standard errors.

No other main effects or interactions were observed when separate analyses were carried out for both the 300 and 500 ms timing conditions**.**

4.2.4 Discussion

As predicted, the results revealed a significant interaction between object type and response type, in both response time data and error data. Consistently with the results emerged in the previous experiments, participants tended to respond faster and more accurately to the names that referred to objects which afforded a grip compatible with the response given.

However, when data were broken down further this interaction was observed only for the early SOA condition of 300 ms and for Rts, suggesting a stronger affordance effect for the shorter SOA.

These results are in line with those obtained in a study by Makris et al. (2011), who used a similar experimental design to explore the time course of affordance related compatibility effects induced by the pictures of manipulable objects. The pictures referred to objects affording either a precision or a power grip and were presented on a screen on a white background. Participants had to categorize them according to a change in the background’s colour (to either blue or yellow) by mimicking precision or power grips. Three different SOAs (400, 800, 1200 ms) were introduced between the onset of the object picture and the background’s colour change. The authors found a significant interaction between object type and response type (i.e., grasp compatibility effects) in the RTs data only in the earlier SOA condition of 400 ms, which is relatively close to the 300 ms SOA condition used in the present study.

This provides further evidence demonstrating, once again, that objects and their names are almost indistinguishable in their ability to evoke and potentiate object-related motor programs. In other terms, the grasp compatibility effects observed seem to behave independently from the format through which the affording objects are presented.

In addition, the results of the present experiment show that this motor potentiation is highest soon after the onset of an object name, and rapidly fades out as time goes by.

In conclusion, these results argue in favour of the idea of an embodiment of language and are in line with all those theories which emphasize the close link that exists between perception, action, and cognition.

The next experiment aimed at confirming and expanding these findings by using a TMS technique to examine what happens when the same object names are presented and no actual response is required.

4.3 Experiment 7

4.3.1 Introduction

As already mentioned, the main purpose of the present experiment was to examine whether semantic information about objects (i.e., objects' size), once again accessed through their written names, could be automatically translated into specific motor activity even in the complete absence of any intention or requirement to act.

One of the most effective way to examine the potentiation of motor activity in the absence of intentional motor action is to trigger activity in the motor system externally, in order to gauge the state of excitability it is in when exposed to objects (or to their names) with different affordances. TMS allows this direct measurement of cortical excitability in motor regions (i.e., TMS used as an on-line probe). Unlike any other method, TMS offers the unique advantage of affecting activity in motor regions of the brain, and measuring its manifestation in the muscles in the complete absence of any requirement to act.

At present, only a few studies have employed a similar methodology to support the notion that the motor system is involved in language processing. For example, Buccino et al. (2005) used TMS during the presentation of action verbs. The authors found a modulation of MEPs in distal limb muscles associated with corresponding effector-specific action verbs. Namely, it was found that MEPs recorded from hand muscles were specifically modulated by listening to hand-action-related verbs, as were MEPs recorded from foot muscles by listening to foot-action-related verbs. Another TMS study has shown that the ventral premotor cortex is involved in the processing of words that refer to tools but not to animals (Cattaneo, Devlin, Salvini, Vecchi, and Silvanto, 2010). In addition, the nouns of manipulable objects (i.e., tools) have been shown to produce greater activity in a hand muscle compared to nouns referring to non-manipulable objects (Gough, Riggio, Chersi, Sato, Fogassi, and Buccino, 2012).

In this experiment, a similar TMS approach was employed. As in all the experiments presented in this thesis, the power and precision component of the grasping action was investigated in relation to the compatibility of an object for grasping with either a power or a precision grasp. This time, however, and unlike most studies reported in the behavioural literature (included the experiments described in this thesis), participants were not required to prepare for any motoric response. They were only asked to read the names of graspable objects for which the action of either pinching or grasping was more appropriate. While reading, participants received TMS over the primary motor cortex representation of the right hand, and muscular responses (i.e., MEPs) were recorded from two intrinsic hand muscles associated with either a precision or a power grip (see Makris et al., 2011 for a similar approach with object pictures).

In addition, similarly to experiment 6 reported in this chapter, different timings of stimulation (i.e., different SOAs) were used in order to further explore the time course of the affordance effects elicited by object names.

If affordance-related motor plans are indeed activated automatically by object semantic knowledge, a significant interaction between the type of object (pinchable or graspable) and the type of hand muscle was expected to be observed. Specifically, activity in the muscle associated with a precision grip was expected to be greater while reading words that referred to objects affording a precision grip. Vice versa, a greater activity in the muscle associated with a power grip was expected when the words referred to objects affording this type of grip.

Moreover, based on the pattern of results emerged in experiment 6 and on some indications provided in literature, a greater response of the motor system to object names in the early SOA conditions was predicted.

4.3.2 Method

Participants

Twenty three new participants (13 females) aged between 18 and 41 years (Mean Age = 23.8; SD = 4.43) took part in the experiment. They were all native British English speakers and right-handed (Mean Laterality Quotient = 86.93; SD =

10.73) as assessed by a revised version of the Edinburgh Handedness Inventory (Oldfield, 1971; Williams, 1986; see *Appendix B*). All participants reported normal or corrected-to-normal vision, as well as no reading, hearing or motor function impairments.

Prior to being considered eligible for the study, the candidates had to complete a series of screening questionnaires to rule out any possible neurological problems, other medical problems or contraindications to TMS. Specifically, they were asked to complete the standard TMS Study Suitability Questionnaire agreed at the 2008 International Consensus Conference in Siena, Italy (Simone Rossi, Mark Hallett, Paolo M. Rossini, and Alvaro Pascual-Leone, 2009), the Depression Anxiety Stress Scale (DASS) questionnaire (Psychology Foundation of Australia, 2013), and the Alcohol Use Disorders Identification Test (AUDIT) (World Health Organization, 2001) (see Appendix E for a complete listing of the screening questionnaires used). After rating the questionnaires, a consultant neurologist approved appropriate participants and obtained their informed consent.

Participants were naïve as to the purpose of the study and received £20/hour for taking part.

The study was approved by the Psychology Department Ethical Committee of the University of Edinburgh and carried out in accordance with the ethical standards of the Declaration of Helsinki (1964).

Stimuli

The stimulus set was the same as that used in the previous experiment.

Single-pulse TMS (spTMS) and electromyography (EMG)

The experiment involved participants reading silently the object names presented visually on a computer screen. During the presentation of each word, participants received spTMS to their left primary motor cortex. Simultaneously, motor evoked potentials (MEPs) were recorded from two intrinsic muscles of the right hand using EMG: two disposable electrodes (30 mm x 24mm) were attached to the First Dorsal Interosseous (FDI), associated with a precision grip, and two electrodes were attached to the Abductor Digiti Minimi (ADM), associated with a power grip (see Figure 4.6 below).

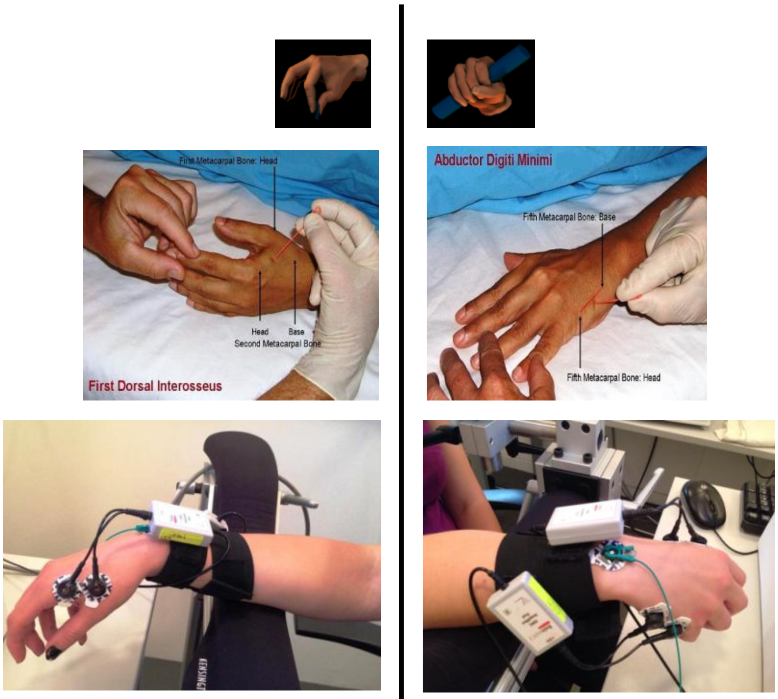


Figure 4.6

<u>Left:</u> First Dorsal Interosseous (FDI) muscle associated with the action of pinching

<u>Right:</u> Abductor Digiti Minimi (ADM) muscle associated with the action of grasping

Muscle activity was amplified and acquired using the Brainsight 2 EMG unit (Brainsight v2.2; Rogue Research Inc, Montreal, Canada) sampling at a rate of 1000 Hz with a band-pass filter applied (16-470 Hz).

TMS was delivered via a 70 mm figure-of-eight standard coil connected to a Magstim Rapid^2 biphasic stimulator (The Magstim Co. Ltd., Whitland, Carmarthenshire, UK). The coil was held tangentially to the skull with its handle pointing backwards/laterally approximately midway between the saggital and coronal planes. A chin and forehead rest was used to minimize head movements and ensure a stable position of the coil over the skull (see Figure 4.7).

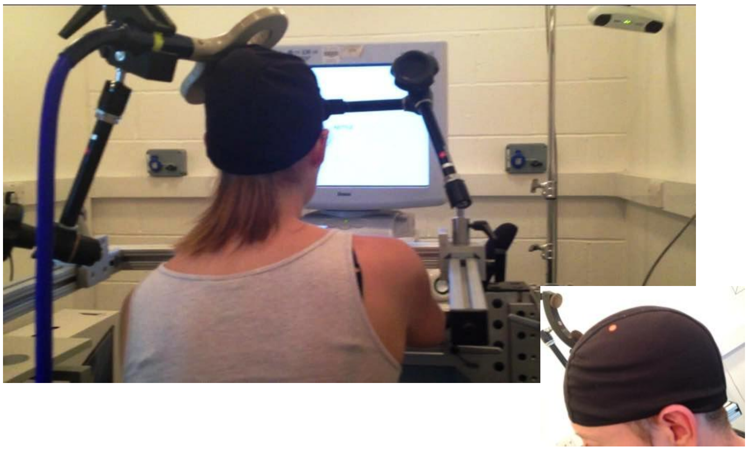


Figure 4.7
Position of the coil over the skull.

The protocol was implemented and controlled by E-Prime Software version 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA, 2009), which allowed to present stimuli and deliver digital TMS signals.

For each participant, the location of the primary motor cortex for activating muscles of the hand was determined prior to the main experiment, and achieved by induction of observable motion using spTMS at a low rate. After finding a location that produced a visible twitch in FDI, the 'resting motor threshold' was determined. It was defined as the lowest stimulation intensity that produced this activation during rest on at least 50% of occasions (Rossini et al, 1994). The position of the coil was then adjusted slightly in order to obtain an average of approximately one millivolt (mV) peak-to-peak MEPs in both FDI and ADM. Participants wore a swimming cap to allow for accuracy in marking the site for stimulation (see Figure 4.7), which was set to be 110% of passive motor threshold during the actual experiment. Across participants, the output of the stimulator ranged from 45% to 90%.

Design and Procedure

The experiment was conducted in a sound attenuated and dimly illuminated room. Prior to starting the experiment, participants were asked to fill in the revised version of the Edinburgh Handedness Inventory, and then to seat comfortably at a distance of approximately 50 cm in front of a 19’’ computer screen with their right hand in a relaxed position. Once determined the site for stimulation and its intensity, the experimental session started.

All participants were presented with written instructions (Appendix C), and attended to 12 ‘practice’ trials before commencement of the main experiment to let them become relaxed and more familiar with it. As illustrated in Fig. 4.8, a blank white screen signalled the start of each trial. Two hundred ms later it was replaced by a black coloured object’s written name (i.e., the prime stimulus) on a white background. The SOA was varied for each of the primes, so that the time between the prime stimulus onset and the delivery of spTMS could be 200, 350 or 500 ms. After a total of 5000 ms, the object’s name disappeared and was replaced by an inter-trial fixation point for 1300 ms.

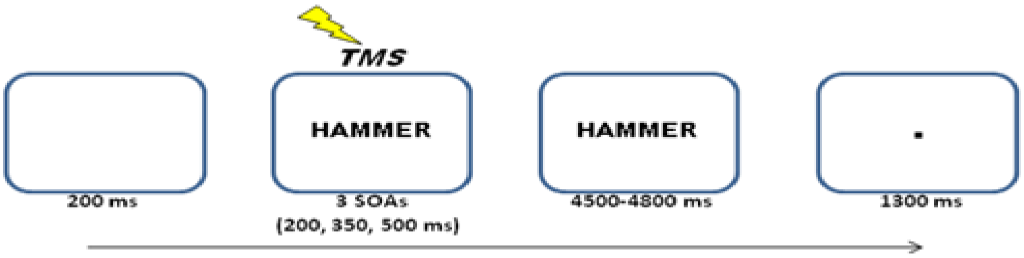


Figure 4.8

Sequence of presentation in a typical TMS trial.

A vigilance task was included to ensure participants to keep attention on the stimuli: during the task a particular tone occasionally was delivered immediately after the presentation of a word, and participants were instructed to respond overtly (i.e., say verbally) if that word referred to a natural or manmade object. Since participants could not know when exactly the tones occurred, they were engaged in categorizing silently the verbal stimuli throughout the experiment, thus the attention paid to stimuli and the kind of elaboration involved were the same of those required in the previous experiments.

As a whole, there were 324 trials: 3 repetitions of each object's name x 18 stimuli per object category (Pinchable, Graspable) x 2 object categories x 3 SOAs, divided into nine blocks of 36 trials. During intervals between blocks, participants were asked to have a break while the position of the coil on the skull was checked. All conditions, including the vigilance trials (36 in total), were presented in a randomized order for each participant.

At the end of the experimental session, participants completed an Adverse Effects Questionnaire (see Appendix F for a sample), which included three simple mathematics and general knowledge questions as well as a rating of the occurrence of any discomforts due to TMS (e.g., headaches, twitching of face muscles, etc.).

Finally, participants were debriefed and compensated for participating.

4.3.3 Results

During the experimental session, and before analysing data, electromyographic activity was carefully checked for any signs of muscular pre-activation that could occur prior to delivering TMS pulses. In addition, it was considered the eventuality that the coil could shift away from its position at any moment during the experiment and cause no MEP activity or no observable motion of the hand muscles. Based on these precautions, and in order to avoid distortions in the analysis, it was decided to exclude the data from five participants who displayed either the former or the latter case (or both cases).

For the data obtained from the remaining eighteen participants, it was calculated the peak-to-peak size of the MEP on each trial, as well as the mean average within each condition for each participant.

These MEP sizes were then entered into a three-way repeated measures ANOVA with graspability (pinchable, graspable), hand muscle (FDI, ADM), and time (200, 350, 500 ms) as within participants factors.

All data were analysed using *SPSS*® version 19.0 (*SPSS* Inc., Chicago, IL, USA).

Before reporting the results of the analysis, it has to be said that no sign that might suggest a seizure had occurred due to TMS was registered. In addition, participants performed good on the tests included in the Adverse Effects Questionnaire (i.e., mathematics and general knowledge questions). The questionnaires also revealed that only four participants experienced mild discomfort which was mainly due to induced muscular twitching on the scalp.

The results from the three way ANOVA showed a significant main effect of hand muscle [F (1, 17) = 12.346; p = .003; η_P^2 = .421] indicating a greater activation of FDI muscle overall, and a significant two way interaction between this factor and time [F (2, 34) = 10.337; p = .000; η_P^2 = .378]. S-N-K post hoc analyses revealed that, compared to the 500 ms timing condition (M = .64 mV; SD = .61), such activation was significantly greater in both the 200 ms timing condition (M = .83 mV; SD = .71), and the 350 ms timing condition (M = .76 mV; SD = .72).

Most importantly, however, the analysis showed a significant two way interaction between graspability and hand muscle [F (1, 17) = 5.080; p = .038; η_P^2 = .230]. S-N-K post hoc tests showed that the names of pinchable objects produced significantly bigger FDI MEPs (M = .757 mV; SD = .68) compared to the names of graspable objects (M = .735 mV; SD = .68). However, MEPs for the ADM muscle were only slightly bigger when participants were exposed to the names of graspable objects (M = .239 mV; SD = .16) compared to the names of pinchable objects (M = .236 mV; SD = .15).

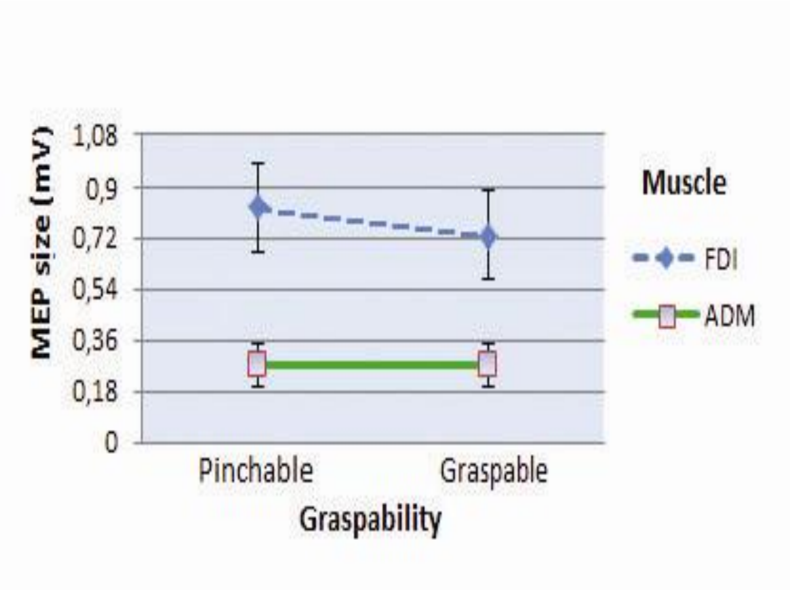
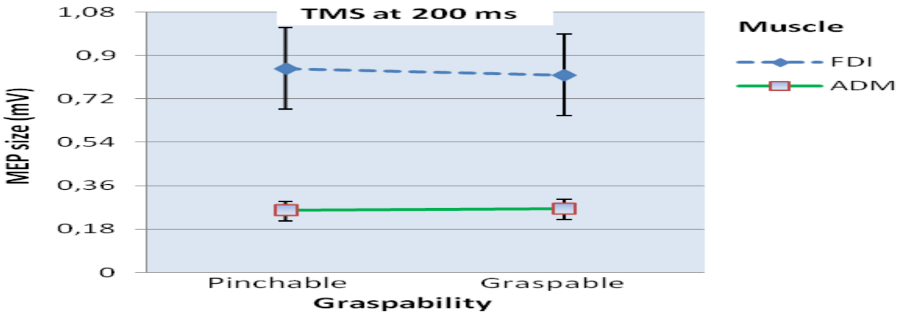
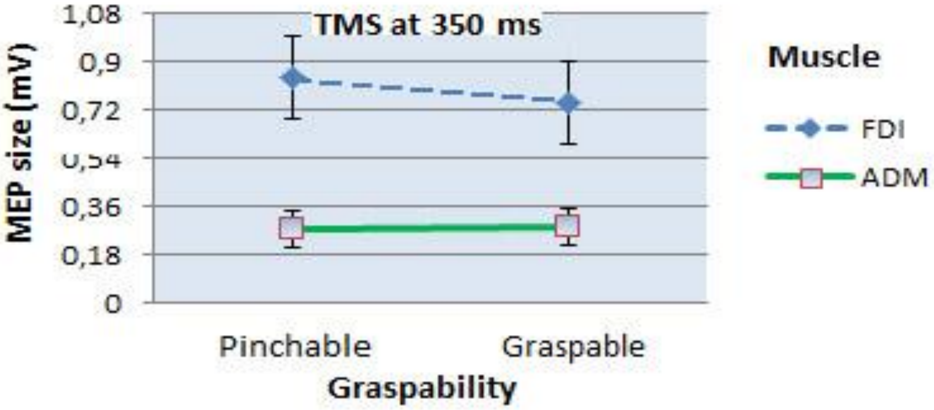


Figure 4.9
Means of peak-to peak MEP sizes for the timing conditions merged (TMS at 200, 350, 500 ms). Error bars denote standard errors.

As in the previous experiment, even though the three-way interaction between graspability, hand muscle, and time was not significant [F (2,34) =.610; p = .549], separate 2 (graspability) x 2 (hand muscle) ANOVAs were conducted for each of the three different timing conditions in an effort to establish which conditions contributed more to the pattern of results obtained.

Even though no significant interactions were found in all timing conditions, the two way interaction between graspability and hand muscle was nearing significance only in the condition where stimulation was delivered 350 ms after the onset of the prime [F (1, 17) = 3.274; p = .08; η_P^2 = .161]. In this condition, the previously described pattern – i.e., greater MEPs for the FDI muscle when reading the names of pinchable objects compared to the names of graspable objects – was more apparent than in both the 200 ms timing condition [F (1, 17) = 1.439; p = .247], and the 500 ms timing condition where the data clearly tended to flatten out [F (1, 17) = .012; p = .913] (see Fig. 4.10).





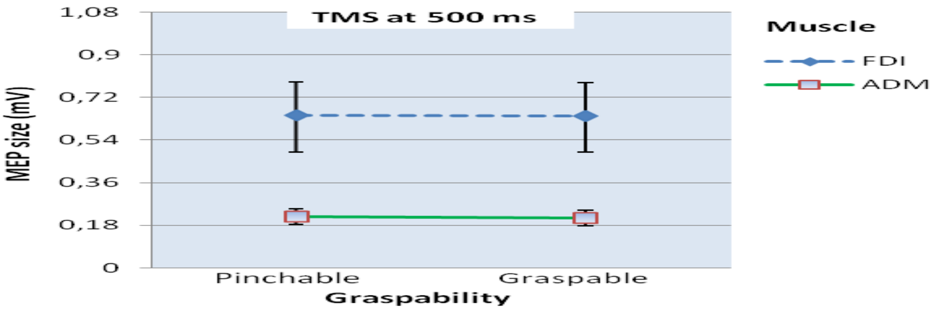


Figure 4.10

Means of peak-to peak MEP sizes for the different timing conditions. Error bars denote standard errors.

4.3.4 Discussion

Consistently with the results shown in experiment 6, a significant interaction between object type and associated hand muscle was observed in the present experiment. Specifically, it was found that the exposition to the names of pinchable objects led to a significantly greater activity in the muscle associated with the compatible precision grip (i.e., FDI muscle), whilst only a marginally bigger activity was observed for the muscle associated with a power grip (i.e., ADM muscle) following exposition to the names of graspable objects.

However, when data were broken down further to examine which of the three timing conditions contributed more to the pattern of results observed, the two way interaction between object type and hand muscle was nearing significance only in the condition where stimulation was delivered 350 ms after the onset of the object name (see section 4.3.3 for more details). More precisely, a trend towards a compatibility effect seemed to emerge in the 350 ms timing condition whilst, on the contrary, it tended to disappear for the stimulating condition of 500 ms post-stimulus presentation. These results seem to confirm the findings of experiment 6 where an overlapping pattern of results was observed. To recap, grasp compatibility effects were observed only in the early 300 ms timing condition, whilst no significant interactions were found in the late time condition of 500 ms.

In addition, the results of experiment 7 mirror those of Makris et al. (2011), who used the same TMS paradigm to investigate the temporal evolution of the motor plans afforded by the pictures of pinchable or graspable objects. Similarly to what observed in the present experiment, they found a significant interaction between object type and associated hand muscle only in the early SOA condition of 300 ms. No affordance effects were observed in the late SOA conditions of 600 and 900 ms. Furthermore, as in their study, the activation and the affordance effect found in experiment 7 were more evident for the FDI muscle than for the ADM muscle. In trying to find an explanation for the greater modulation of motor excitability for the FDI muscle, the authors hypothesise that this muscle might reasonably contribute to both precision and power grasps, while the ADM muscle is probably only involved in whole-hand grips. However, if one takes into account the results of the previous behavioural experiments where the compatibility effects seemed to be more evident for the power responses, then the interpretation put forward by the authors appears weak. An alternative explanation could be linked to the particular stimulation technique employed in both TMS studies. Specifically, the stimulation of the motor cortex for activating both hand muscles was delivered via a 70 mm standard figure-of-eight or ‘butterfly’ coil which was positioned in a location that produced a visible twitch in both FDI and ADM muscles. It might be possible that in this specific location of the primary motor cortex the representation of the FDI muscle is slightly more extended than that of the ADM muscle, which might have increased the probability of stimulation and activation of the former. Further research is required to verify this possibility. For example, the use of smaller and more sophisticated coils able to produce a more confined magnetic flux, thus to enhance the stimulation focality (e.g., by reducing the diameter of the coil windings or by improving their shape) (see, for example, Yunokuchi and Cohen, 1991; Hernandez-Garcia, Hall, Gomez and Michielssen, 2010) could shed some lights on this issue. In any case, the interaction found rules out any explanation in terms of non-specific activation of the responding hemisphere by the graspable object names.

Taken together, these data show that the affordance-related motor-cortical activity induced by object names displays a temporal evolution very similar to that emerged during perception of object pictures. It seems that as soon as an object is identified (visually or through its name), the motor information it contains is rapidly translated into object compatible motor plans. Such a motor potentiation occurs automatically, without the need to prepare for any motoric response. However, it seems to fade out with the same rapidity with which it is activated. In addition, once again, the present results are in line with the indexical hypothesis (Glenberg and Robertson, 2000) according to which words are deeply linked to their actual referents and support an embodied view of language which proposes that during language processing of an object word, the perception and action systems activated are the same as when observing or actually interacting with the object to which the word refers.

4.4 General Discussion

The results provided in this chapter have demonstrated anew that semantic processing of the names referring to manipulable objects can modulate the motor system in a way similar to that observed when their actual referents are presented physically or in a pictorial form.

Such a modulation was apparent using two different methodologies for examining the state of the motor system, one based on speeded responses (experiment 6) and the other based on corticospinal excitability (experiment 7). In this latter case, specifically, it was taken advantage of the spatial and temporal specificity of TMS to measure excitability of the primary motor cortex hand area following the presentation of the names of objects affording hand actions. This methodology, therefore, allowed to examine the response of the motor system to object names directly from its muscular manifestation in the absence of any intentional motor action or motor preparation.

The present data suggest that the motor information about objects, once accessed and activated through their verbal labels, is automatically translated into specific object related motor plans. Thus, such a motor potentiation occurs rapidly and without the need to prepare for any motoric response. This finding is consistent with previous evidence showing that the motor system is automatically recruited at an early time point following presentation of pictures of manipulable objects (see, for example, Buccino, Sato, Cattaneo, Rodà, and Riggio, 2009; Makris, Hadar, Yarrow, 2011), action verbs (Buccino, Riggio, Melli, Binkofski, Gallese, and Rizzolatti, 2005), and tool nouns (Cough, Riggio, Chersi, Sato, and Fogassi, 2011; see, also, Cattaneo, Devlin, Salvini, Vecchi, and Silvanto, 2010).

In addition, a consistent finding from both the experiments presented in this chapter is that grasp compatibility effects are observed soon after the onset of the object name (i.e., in a time window of 200-500 ms), but are suppressed thereafter. This provides some initial indications about the time course with which affordance related motor activity develops during language processing of object names. Indeed, so far, nothing or little was known about this aspect. At present, this is the first work that seeks to investigate the temporal evolution of affordance effects elicited by linguistic material by using two different experimental measures.

Nevertheless, it has to be considered that the lack of a three way interaction between object type, hand muscle, and time does not allow to make unequivocal claims about the existence of affordance effects in the early but not late time points. However, as previously discussed, the pattern of results emerged here is completely in line with the TMS study by Makris et al. (2011), in which very similar results were found during observation of pictures of manipulable objects.

Taken together, the present findings strongly contribute to highlight the similarity between objects and their names in their ability to automatically recruit the motor system and evoke object related motor programs. Additionally, they show that the specific motor patterns evoked during semantic processing of object names follow the same temporal evolution of the motor patterns activated during perception of objects. Such similarities are in closer alignment with all those theories which emphasise a close relationship between perception, action, and cognition. For instance, as often reported, the embodied approach to language posits that during language processing of object names the same perception and action systems are recruited as when interacting with the actual objects. Also, this in line with the neural exploitation hypothesis (Gallese and Lakoff, 2005; Gallese, 2008; Glenberg, 2008), a model of neural re-use (Anderson, 2010), which proposes that, since evolution is conservative, language relies on phylogenetically preexistent systems, such as the action system and, therefore, reflects some characteristics of action organization.

Similar evolutionary theories of human cognition and action could be taken into account in an effort to explain the finding that object names, like their referents, are able to automatically and rapidly activate object related motor plans which dissipate with the same rapidity as times goes by. From an evolutionary perspective, survival in a hostile environment may require immediate action by activating movements that are, at least partially, prepared. In this sense, affordances for action should be evoked rapidly. Their rapid suppression could be explained by hypothesising that maintaining such plans for action may be resource demanding, thus metabolically (and evolutionary) uneconomical.

Alternatively, one could take into account the ‘affordances competition hypothesis’ proposed by Cisek (2006, 2007) in his model of motor decision making. According to this hypothesis, several motor plans are automatically activated in response to the multiple stimuli present in the environment. Since only the motor plans towards directly available targets are chosen to be further processed and finally executed, it is hypothesised that the ‘discarded’ afforded plans for action are actively eliminated at a quite early stage through a mechanism of competition and mutual inhibition.

Summing up, the present work has demonstrated that the names referring to manipulable objects are able to activate action-relevant object information and recruit the motor system in the same way as when their referents are perceived or actually handled. Such motor information is automatically translated into specific motor activity, even in the total absence of any intention to act. Finally, this motor potentiation seems to be rapid and relatively short lived.

Chapter Five

Our capacity to use tools and objects is often considered one of the hallmarks of the human species. Successful interaction with objects in the environment is the precondition for our survival and for the success of our attempts to improve life by using artefacts and technologies to better adapt to our environment and to transform it. Indeed, we continuously surround ourselves with objects that greatly extend our bodily and cognitive capabilities to act in the physical world. For example, driving a car or riding a bike significantly increase our physical action radius; a mobile phone enhances our capacity for long-distance communication; and a calculator offloads the need for mental calculation.

The question of how the brain ascertains what interactions are appropriate for different objects is one of the major issues in the field of experimental psychology and cognitive neurosciences. One fruitful approach, the ecological approach to perception (Gibson, 1979), has proposed that perceptual systems are naturally tuned to pick up on various objects' affordances. According to the affordance account, simply viewing an object can activate object-related motor plans. In other words, observing an object would lead to the selection and activation of the movements aimed at appropriately and efficiently acting upon it (see, for example, Bub and Masson, 2010; Costantini, Ambrosini, Tieri, Sinigaglia, and Committeri, 2010; Ellis and Tucker, 2000; Tucker and Ellis, 1998, 2001, 2004). Such specific motor activations – also referred to as micro-affordances (Ellis and Tucker, 2000) – have typically been demonstrated behaviourally by means of the compatibility effects: participants are faster or more accurate at making motor responses that are congruent with those that would be appropriate for handling an object to which they are exposed.

Micro-affordance compatibility effects have been reported for several different object properties and components of the reach-to-grasp action (e.g., for object orientation, weight, etc.) during both on-line and off-line visual processing. In the present thesis, the power and precision component of the grasping action was investigated in relation to the compatibility of an object for grasping with either a power or a precision grasp. A stimulus-response compatibility paradigm was employed to examine the presence of such grasp compatibility effects during both the categorization of visual objects and the language processing of object names.

In the next section a summary of the major experimental findings is provided together with a final discussion on the main theoretical implications of the results presented.

5.1 Major Experimental Findings and Final Discussion

In experiment 1, evidence was sought for grasp compatibility effects arising while observing and categorizing the pictures of manipulable common objects. The objects were compatible with either a power grip or a precision grip. Participants were asked to categorize each object presented as either natural or manmade, and to give their responses by using a special manipulandum able to mimick precision and power grips. Depending on the mapping rule given, they had to press either a 'power grip switch' if the object was manmade or a 'precision grip switch' if the object was natural, and vice versa. Differently from most micro-affordance studies where objects were typically presented with their natural or real-world proportions preserved (i.e., objects that are usually picked up by pinching smaller than objects that are picked up by grasping), in this experiment the objects' on-screen size was balanced so that all objects, regardless of their real size, were displayed in approximately the same size. Such a new manipulation aimed at examining whether the activation of the motor programs associated with objects' affordances necessarily relies on the processing of their on-line visual properties, as would be expected if this mechanism were controlled by on-line dorsal processes. Consistently with the results of previous studies which report micro-affordance effects for seen objects associated with a power or a precision response, in experiment 1 significant interactions were observed between object type (pinchable, graspable) and response type (precision, power) in both the response time data and in error data. The emergence of such grasp compatibility effects even in this experiment, where no immediate visual information about objects' size was available, suggests that the processing of an object's on-line visual properties is not a necessary requirement for affordance compatibility effects to be induced. Instead, this leads to hypothesise that the process responsible for their generation might be linked more to the objects' off-line representations and the associated action-related knowledge than to the specialised on-line visuomotor processes typically associated with the activity of the dorsal system.

As a stronger test of this hypothesis, in experiments 2 and 3 the names (written or spoken respectively) of those same objects presented pictorially in experiment 1 were used in order to examine whether an object needs to be currently and visually present for activating the motor programs associated with its affordances. The results indicated that grasp compatibility effects can emerge whether or not an object is being seen or identified through its verbal label. It seems that the concurrent presence of a visual object is not necessary to prime a particular type of grasp, and that the identification of an object, through either its picture or its name, is sufficient to activate appropriate object representations and the associated motor responses. Once again, this finding suggests that the process responsible for the generation of affordance-based motor priming does not always depend on the transient on-line visuomotor processing associated with the activity of the dorsal system. Rather, what appears to be critical for the expression of such effects are long-term object-action associations that are known to be under the remit of the ventral system.

Moreover, the use of the same experimental paradigm as well as of the same stimuli in the three experiments reported in chapter 2 allowed to make a direct comparison between the experiments, thus to examine how micro-affordance effects behave when objects are presented in different formats and through different sensory modalities. Such a comparison showed that the three experiments produced similar and statistically indistinguishable results. The presentation mode did not have any impact on the effects observed, suggesting that the compatibility effects arisen from the power and precision components of the grasping action behave independently from the format or sensory modality through which the affording objects are presented. This in turn would suggest that a common neural substrate might be active and responsible for the expression of affordance related effects, regardless of whether objects are presented by pictures or words. These results are consistent with those of functional neuroimaging studies showing that the representations of objects, and the associated action-related information, are automatically accessed upon identification, regardless of format (pictures, words) or sensory modality (visual, auditory) through which objects are presented (for reviews, see Bookheimer, 2002; Martin and Chao, 2001; Thompson-Schill, 2003; Martin, 2001, 2007). Indeed, these studies demonstrate that a common neural substrate is active regardless of whether objects are represented by pictures or words, which provides support for interpretations appealing to conceptual and/or lexical processes rather than visual feature processing per se. Interestingly, the neural circuit individuated, that is the left ventrolateral prefrontal cortex and the ventral and lateral regions of posterior temporal cortex, corresponds, to a large extent, to the neural ventral pathway described in chapter one.

The first three experiments reported in this thesis seem to rule out any necessity for visual inputs to be present for micro-affordance effects to be induced. Nevertheless, experiments 2 and 3, as well as previous studies that have sought to investigate such effects by using object names (e.g., Tucker and Ellis, 2004), left open the possibility that visual mental imagery could mediate their expression. This possibility was considered even in light of the fact that affordance-based compatibility effects have been found to emerge even during off-line visual processing of objects, that is when objects are imagined or remembered (Derbyshire, Ellis, and Tucker, 2006).

Experiment 4, described in chapter 3, was carried out with the specific aim to address this issue. In this experiment, the same methodology and stimuli of experiment 3 were used. Participants were acoustically presented with a series of object names and asked to carry out a stimulus-response categorization task. At the same time, however, they were exposed to irrelevant visual stimulation, that is to a flickering random array of black and white dots on the screen termed dynamic visual noise (DVN) that has been shown to selectively interfere with individuals' visual processing (Quinn and McConnell, 1996). Such an interfering technique was used in order to inhibit participants' capacity to form the visual mental reproductions of the objects to which words referred.

The results revealed the presence of micro-affordance compatibility effects even following disruption of visual processing. In addition, no significant differences were found when comparing the compatibility effects observed in experiment 4 with those obtained in experiment 3 where no visual interference was employed.

These data point to rule out an involvement of any form of visual processing in the affordance effects observed with objects' names. They suggest that language processing of words that refer to graspable objects is sufficient to access and activate their representations, which contain specific object-related action encodings that are responsible for the generation of compatibility effects related to their grasping affordances. Such a mechanism occurs by simply hearing (or reading) object names, without the need neither to form nor to visually process the visual mental images of their referents.

In experiment 5, a similar interfering approach was employed in order to investigate the contribution of the semantic system to the generation of grasp compatibility effects. Participants were presented with the same verbal stimuli used in experiment 2 (i.e., object written names) and had to perform exactly the same stimulus-response categorization task. Meanwhile, however, they were acoustically exposed to an irrelevant speech (i.e., a reading from a book written in Hebrew, a language unknown to participants) in order to tax semantic processing (e.g., Salamé and Baddeley, 1982; Quinn and McConnell, 1996; Oswald et al., 2000). The results failed to show grasp compatibility effects in both reaction times and errors suggesting that the irrelevant speech technique was effective in producing interference with both verbal and semantic processing (e.g., Martin, Wogalter, and Forlano, 1988), which probably prevented a deep elaboration of the object names, thus a full access to object representations and to object action knowledge necessary for the emergence of grasp compatibility effects.

These data provide further evidence in favour of the proposal that cognition is intimately connected to the motor system. In particular, they suggest that the semantic system and its intact functioning might be essential for the generation of such effects. The results provided additionally suggest, together with the results of experiment 4, that object representations necessary to elicit the effects need not be visual in nature but could be semantic or ‘propositional’, that is more linked to stored semantic knowledge of the object and its associated actions than to its detailed visual properties. This does not mean that object concepts are conceived of as abstract symbols that are arbitrary linked to their referents in the world as proposed by the traditional propositional theories of conceptual representation (e.g., Fodor, 1998; Collins and Loftus, 1975; Laundauer and Dumais, 1997; Foltz, Kintsch, and Laundauer, 1998). Rather, the interpretation put forward here proposes that object concepts are closely related to their referents. However, this relationship might not always be visual or analogical as the classical vision- or image-based view of representation states (e.g., Paivio, 1972; 1991; Kosslyn, 1980; Marr, 1982; Prinz, 2002). The results presented so far suggest that object semantic representations activated during language processing of object names contain specific object-related action encodings built up from a history of past interactions with objects that have become integrated with object representations and are responsible for the emergence of the compatibility effects observed. They contribute to support previous theories and studies that suggest that objects are represented in terms of the actions they elicit (e.g., Grafton, Fadiga, Arbib, and Rizzolatti, 1997; Gallese, 2000; Chao and Martin, 2000; Gerlach et al., 2002; Grezes, Tucker, Armony, Ellis, and Passingham, 2003). Therefore, the view outlined here is still situated within an embodied and grounded view of knowledge and conceptual representation. As previously mentioned, according to this perspective knowledge is grounded in sensorimotor processes and knowledge acquisition and use are influenced by the characteristics of our body and its peculiar way to interact with the environment. Within this view, conceptual information is distributed over modality specific domains (Barsalou, Simmons, Barbey, and Wilson, 2003; Boronat, Buxbaum, Coslett, Tang, Saffran, Kimberg, and Detre, 2005; Gallese and Lakoff, 2005; Martin, Wiggs, Ungerleider, and Haxby, 1996). Thus, thinking of an object or of an entity leads to a re-experiencing (i.e., a simulation) of the interaction with that object or entity. For example, thinking of a dog leads to the activation of multimodal information, for example the sound of the dog barking, its colour and shape, the smoothness of its fur while we caress it, etc. So, concepts are conceived of as ‘simulators’, as they make it possible to run simulations (Barsalou, 1999; Barsalou et al., 2003) that consist of re-enactments of our sensorimotor experiences with objects and entities. Namely, the neural areas recruited when we think about an object or an entity and prepare to act are the same that are recruited when we perceive and interact with its referent. Adopting an embodied view of concepts implies a rejection or a revisitation of the image-based view of representation. The image-based and the embodied theories of concepts share the idea that concepts are not amodal, abstract, arbitrary and propositional symbols. However, while sustainers of the image-based view consider concepts exclusively as visual or analogical representations of their referents, proponents of the embodied cognition perspective revisit the notion of ‘mental imagery’ or ‘mental representation’ in purporting that concepts cannot be equated to stable and constant ‘visual images’. Concepts are not holistic representations, but they are componential in nature because they result from the activation of different modality specific features across different domains. There is compelling evidence showing that information is distributed in the brain across modality specific areas, and that information related to different features is stored in different brain regions (e.g., Martin et al. 1996; Boronat et al., 2005). In other terms, concepts imply the simultaneous activation not only of visual but also of tactile, motor, acoustic, taste features. In order to be productive, the semantic system must be componential, and its components are different kinds of features distributed in different brain areas. The results of an elegant study by Pecher, Zeelenberg and Barsalou (2003) clearly favour the idea that concepts imply the simultaneous activation of different modality specific domains. The authors selected concept nouns and properties regarding vision, motor action, audition, taste, touch and smell. Participants were presented with a sentence like ‘this lemon is sour’ and they had to indicate if the property in the sentence (e.g. sour) was true or false for that particular object or entity (e.g. lemon). The results showed that when participants had to switch modality to respond, for example from a property related to taste (e.g.: ‘this lemon is sour’) to an auditory property (e.g.: ‘the mixer is noisy’), response times were slower. This shows that different properties can be activated across different modalities and that switching from a modality to another implies a cost (modality switch effect). A control experiment ruled out the possible alternative explanation that amodal symbols for the same modality were more associated than amodal symbols for different modalities. There is also evidence on cortical object representation showing that manipulable objects, unlike non-manipulable objects, activate motor-related areas, whereas animals activate vision-related areas (e.g., Gerlach, Law, and Paulson, 2002). As should be clear from this discussion, within the embodied perspective the notion of ‘concept’, ‘mental image’ or ‘mental representation’ is not limited to the visual domain. In this view, the role played not only by perceptual but also by sensorimotor processes for conceptual representation is underlined. In particular, in the last years many studies have focused on the relevance for concepts of motor information and of ‘motor imagery’ (Glenberg, 1997). Indeed, the diffusion of studies on motor imagery and motor resonance processes has contributed to change and extend the meaning of the term ‘motor image’: whereas this term classically referred to explicit or conscious visual representation of an action (e.g., imagining oneself or yourself handling an object), recent research focuses also on implicit or unconscious aspects, and the term ‘motor images’ refers rather to subliminal and specific activations of the motor system (Jeannerod and Frak, 1999). The results of our studies are consistent with the findings reported in this strand of research.

The experiments described in chapter 4 were carried out in an effort to provide initial information about the time course with which affordance related motor activity develops during language processing of object names.

In experiment 6, the experimental design employed was again based on a stimulus response compatibility paradigm. Participants were exposed to the written names of manipulable objects and asked to categorize them by making precision or power responses. Unlike the previous experiments, however, their response had to be given exclusively when the object name changed colour from black to green. The modified version of the experimental design allowed to introduce two different stimulus onset asynchronies (SOAs: 300, 500 ms) between the visual onset of the object name and the time point in which a response was required, thus to examine the response of the motor system at different time points.

The results revealed the presence of grasp compatibility effects only in the early SOA timing condition, indicating that the motor potentiation afforded by object names is highest soon after the onset of the stimuli and rapidly fades out as time goes by.

In experiment 7, a different experimental methodology was employed to examine whether semantic information about objects, once again accessed through their verbal labels, could be automatically translated into specific motor activity even when no response or movement at all was required. Specifically, single-pulse Transcranial Magnetic Stimulation was administered to participants’ primary motor cortex representation of the right hand, time locked to playing them a series of object written names for which the action of either pinching or grasping was more appropriate. Simultaneously, motor evoked potentials were recorded from two intrinsic hand muscles associated with either a precision or a power grip. This methodology, therefore, allowed to examine the response of the motor system to object names directly from its muscular manifestation in the complete absence of any intentional motor action or motor preparation. In addition, similarly to experiment 6, three different timings of stimulation (200, 350, 500 ms) were used in order to further explore the temporal evolution of the affordance effects elicited by object names.

The results revealed a significant interaction between object type and associated hand muscle. The exposition to the names of pinchable objects led to a greater activity in the muscle associated with the compatible precision grip. Similarly, a marginally bigger – although not significantly – activity was observed for the muscle associated with a power grip following exposition to the names of graspable objects. Interestingly, in line with the results of experiment 6, the trend observed was more evident in the condition where stimulation was delivered 350 ms after the onset of the object name, whilst it clearly faded out in the late SOA condition of 500 ms.

Overall, the experiments reported in chapter 4 indicate that semantic information about objects, once accessed and activated through their names, is automatically translated into specific object related motor plans, even in the absence of any intention or requirement to act. Such a motor potentiation seems to occur rapidly soon after the onset of the object name (i.e., in a time window of 200-500 ms), and to decay thereafter. These results are completely in line with the findings of a study by Makris et al. (2011), who used similar methodologies for examining the state of the motor system following presentation of object pictures, one based on speeded responses (as in experiment 6) and the other based on corticospinal excitability (as in the TMS experiment).

Some authors have argued that such congruency effects and the recruitment of the motor system might not necessarily reflect core features of the conceptual process itself but rather might be the result of secondary activation (e.g., Bub et al., 2008; Page, 2006). For example, the finding that semantic decision times are faster when the response grip and object affordance are congruent than when they are incongruent might not necessarily show that affordances contributed to conceptual or semantic processing of the object. Rather, it might show only coactivation of affordances *after* processing semantic features of the object. Thus, even though affordances have been activated, they might not be necessary for the semantic representation of the object but merely be a byproduct of semantic processing. According to this perspective, the activation of sensorimotor systems would be exclusively due to a mechanism of ‘spreading activation’ to cerebral areas not essential for language processing and comprehension (Mahon and Caramazza, 2008). However, evidence from interference studies speaks against this explanation. In these studies, a concurrent task that occupies the motor system is shown to affect cognition (Busiello, Costantini, Galati, and Committeri, 2011; Casteel, 2011; Dijkstra, Kaschak, and Zwaan, 2007; McCloskey, Klatzky, and Pellegrino, 1992; Paulus, Lindemann, and Bekkering, 2009;Witt, Kemmerer, Linkenauger, and Culham, 2010). For example, Busiello and collaborators (2011) found reduced repetition priming for actions when participants concurrently performed a hand motor task. This finding indicates that the motor task interfered with creating a memory representation and thus suggests that mental representations for actions rely on activation of motor affordances. Casteel (2011) argued that whether action and conceptual processing interfere depends on the timing of the two processes. In particular, interference is found when the two processes are performed in parallel. Rueschemeyer et al. (2010) showed that such interference effects occur when participants performed intentional actions but not when they performed passive actions (i.e., when the finger was forced to move by a device). Interference effects on performance provide evidence that motor affordances contribute to comprehension because they show that when it is harder to activate motor affordances, comprehension suffers. Therefore, affordances should not be considered mere side-effects of language processing. As is clear, similar arguments have contributed to raise the debate concerning the degree to which motor knowledge and the activation of sensorimotor processes support higher cognitive processes such as language processing and comprehension. In trying to find counter-evidence for the theories that interpret the activations of sensorimotor systems as an epiphenomenon or as the result of a spreading activation, in the last years sustainers of the embodied perspective have provided some convincing demonstrations that these activations are not secondary but automatic, specific, and somatotopically distributed. In addition, using different research techniques, it has also been shown that the motor system is recruited at early time points (see Pulvermuller, 2002, for a review). For example, with respect to the degree of specificity of the neural patterns activated during language processing, Pulvermüller, Härle and Hummel (2001) investigated brain activity elicited by visually presented verbs that could be referred to movements of different body effectors such as arms (e.g., to write), legs (e.g., to walk) or mouth (e.g., to talk). Brain activity was recorded using Event Related Potentials (ERPs), that is a measure of the electrical activity produced in response to a sensory stimulus or associated with the execution of a motor, cognitive, or psycho-physiologic task. ERPs revealed that different kinds of verbs referring to actions performed using different effectors led to the activation of different regions of the brain suggesting a specific somatotopical organization. These data are confirmed in a behavioural study by Scorolli and Borghi (2007). The authors presented participants with pairs of nouns and verbs that could be referred to either hand and mouth actions (e.g., to unwrap vs. to suck the sweet) or to hand and foot actions (e.g., to throw vs. kick the ball). Their task consisted of deciding whether the combination made sense or not: a group of participants responded by saying yes loudly into a microphone, another group by pressing a pedal. Results revealed a facilitation in responses to ‘mouth sentences’ and ‘foot sentences’ compared to ‘hand sentences’ in case of congruency between the effectors – mouth and foot – involved in the motor response and in the sentence. They suggest that sentence processing activates an action simulation and that this motor simulation is specific as it is sensitive to the effector involved. Furthermore, using a TMS technique during the presentation of action verbs, Buccino et al. (2005) found a specific modulation of MEPs in the muscle of a given effector (i.e., arm or leg) when it was associated with the verb presented. Given that TMS, when used as an online probe of the cortical excitability, allows to affect activity in motor regions of the brain and measure its manifestation directly in the body muscles in the complete absence of any requirement to act, this study additionally suggests that the motor system is automatically recruited. As already reported, the results of other studies that employ a similar methodology confirm both the automaticity and the specificity of the motor system and further indicate that it is recruited at an early time point after stimulus presentation, namely in a time window that ranges approximately from 150 to 400 ms (see for example, Cough, Riggio, Chersi, Sato, and Fogassi, 2011; Cattaneo, Devlin, Salvini, Vecchi, and Silvanto, 2010). In complete alignment with these findings, the studies presented in chapter 4 provide additional evidence that the semantic and motor systems are strictly interwoven. In particular, they show that only processing words referring to objects that have a significance for the actions of pinching and grasping can lead to an automatic activation of the motor system. Importantly, the data indicate that this activation is specific as shown by the greater modulation of the hand muscles examined in response to object names that afford a compatible hand action. The fact that affordance related activity has been shown separately for two closely-related motor plans that coexist within a very small portion of the same brain hemisphere further suggests that the motor system is highly and somatotopically organized. These results, together with the finding that the recruitment of the motor system seems to be observed in the early but not late time points after stimulus onset, point to rule out alternative explanations put forward by sustainers of the 'spreading- or secondary-activation hypotheses'.

More generally, the results of the experiments discussed in the present thesis provide further evidence that the sensorimotor system is intimately connected to higher cognitive systems, such as the semantic and language systems. In line with the embodied and grounded approach to cognition, they show how the relationship between object concepts and their concrete referents in the word, far from being arbitrary as assumed by traditional cognitive sciences, is the direct product of our specific past sensorimotor experiences with them. Indeed, it has been shown, with different methodologies, that during language processing of object names the sensorimotor processes recruited seem to be the same as those involved when individuals experience the actions or objects to which words refer (for a similar point of view, see Barsalou, 1999; Fisher and Zwaan, 2008; Glenberg, 1997; Lakoff, 1987; Pulvermuller, 2002; Zwaan and Taylor, 2006; Zwaan, 2004). The similarity highlighted here can be read in terms of recent evolutionary theories of human behaviour and action emerging in the embodied cognition literature. In particular, it seems to be in closer alignment with the neural exploitation hypothesis (Gallese and Lakoff, 2005; Gallese, 2008; Glenberg, 2008), a model of neural re-use (Anderson, 2010), according to which, since evolution is conservative, language would rely on phylogenetically preexistent systems, such as the perception and action systems and, therefore, would reflect some characteristics of their organization.

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Appendices

Appendix A

List of objects[10] used in:

- **experiments 1-5**

Power compatible		Precision Compatible	
Natural	Manmade	Natural	Manmade
APPLE	BOTTLE	Almond	Coin
Apricot	BRUSH	Berry	Earring
Aubergine	CANDLE	Blackberry	Eraser
BANANA	COMB	Blueberry	Lighter
Beetroot	CUP	CHERRY	LOCK
CARROT	FLAG	Cranberry	Match
CELERY	GLASS	Garlic	NEEDLE
Courgette	Hairdryer	GRAPE	PEN
Cucumber	HAMMER	Hazelnut	PENCIL
Grapefruit	IRON	MUSHROOM	Pendant
Kiwi	Jar	NUT	Pill
LEMON	Jug	Nutmeg	Pin
Lime	KETTLE	Olive	Pushpin
Mango	KNIFE	ONION	RING
Nectarine	Microphone	PEANUT	SCREW
ORANGE	Saucepan	Pecan	Sharpener
Parsnip	Sieve	Plum	Spike
PEACH	Spatula	Raisin	Teaspoon
PEAR	Stapler	Raspberry	THIMBLE
PINEAPPLE	Teapot	Redcurrant	Thread
POTATO	TELEPHONE	Rice	Ticket
Tangerine	Torch	STRAWBERRY	Toothpick
Turnip	UMBRELLA	Walnut	Tweezers

---

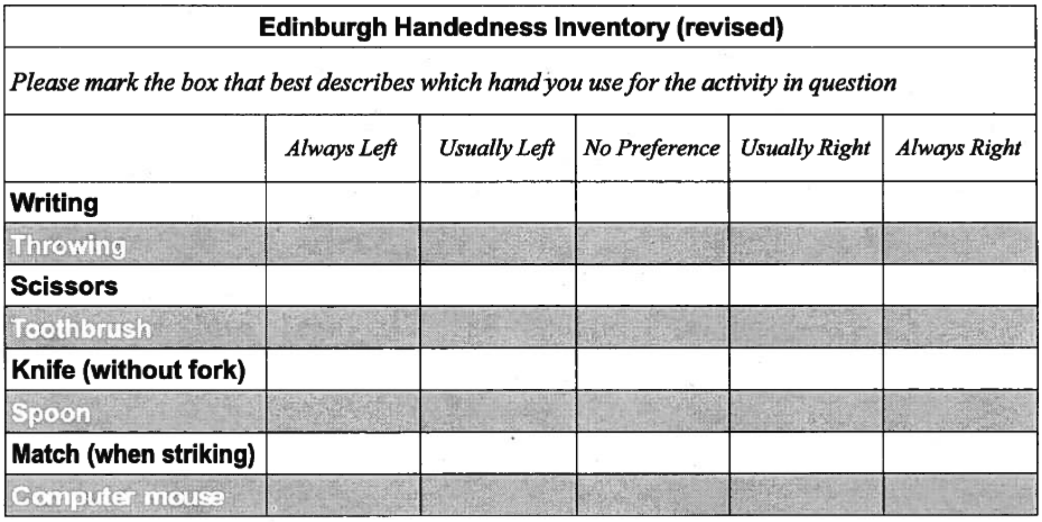
[10] Note that only the objects reported in upper case letters were available in the Snodgrass and Vanderwart's (1980) picture set.

- **experiments 6-7**

Power compatible		Precision Compatible	
Natural	Manmade	Natural	Manmade
Apple	Bottle	Almond	Coin
Banana	Brush	Cherry	Lock
Carrot	Candle	Garlic	Match
Lemon	Glass	Grape	Pencil
Mango	Hammer	Olive	Pendant
Orange	Kettle	Onion	Pushpin
Peach	Knife	Peanut	Ring
Potato	Spatula	Pecan	Screw
Turnip	Stapler	Raisin	Spike

Appendix B

Handedness Questionnaire used in all the experiments (Oldfield, 1971; Williams, 1986)



Edinburgh Handedness Inventory (revised)

Please mark the box that best describes which hand you use for the activity in question

	Always Left	*Usually Left*	*No Preference*	*Usually Right*	*Always Right*
Writing					
Throwing					
Scissors					
Toothbrush					
Knife (without fork)					
Spoon					
Match (when striking)					
Computer mouse					

Appendix C

Instructions given in:

- **experiment 1 for the mapping condition one**

Welcome to the experiment!

You will see a fixation point followed by an image.

Depress the switch with your index and thumb if the image refers to a natural object (e.g., flower, gooseberry, squash), or squeeze the cylinder between the palm and the remaining three fingers if the image refers to a manmade object (e.g., whisk, plug, saw).

Keep your eyes on the fixation point all the time.

Answer as fast and accurately as possible.

Say YES to start the practice block

- **experiments 2 and 5 for the mapping condition one**

Welcome to the experiment!

You will see a fixation point followed by a word.

Depress the switch with your index and thumb if the word refers to a natural object (e.g., flower, gooseberry, squash), or squeeze the cylinder between the palm and the remaining three fingers if the word refers to a manmade object (e.g., whisk, plug, saw).

Keep your eyes on the fixation point all the time.

Answer as fast and accurately as possible.

Say YES to start the practice block

- **experiment 6 for the mapping condition one**

Welcome to the experiment!

You will see a fixation point followed by a black-coloured word.

Depress the switch with your index and thumb if the word refers to a natural object (e.g., flower, gooseberry, squash), or squeeze the cylinder between the palm and the remaining three fingers if the word refers to a manmade object (e.g., whisk, plug, saw).

IT IS IMPORTANT YOU TO GIVE YOUR RESPONSE AS SOON AS THE WORD BECOMES GREEN.

Keep your eyes on the fixation point all the time, and answer as fast and accurately as possible.

Say YES to start the practice block

- **experiments 3 and 4 for the mapping condition one**

Welcome to the experiment!

You will see a fixation point, then you will hear a word.

Depress the switch with your index and thumb if the word refers to a natural object (e.g., flower, gooseberry, squash), or squeeze the cylinder between the palm and the remaining three fingers if the word refers to a manmade object (e.g., whisk, plug, saw).

Keep your eyes on the fixation point all the time.

Answer as fast and accurately as possible.

Say YES to start the practice block

- **experiment 7**

Welcome to the experiment!

You will see a fixation point followed by a word. During the presentation of each word you will receive a single TMS pulse.

YOUR TASK CONSIST OF SIMPLY READING EACH WORD ON THE SCREEN.

Nonetheless, occasionally, you will hear a beep after the presentation of the word. In that case, you have to decide and say if the last word read refers to either a natural object (e.g., flower, gooseberry, squash) or a manmade object (e.g., whisk, plug, saw).

Keep your eyes on the fixation point all the time.

Say YES to start the practice block

Appendix D

The Vividness of Visual Imagery Questionnaire (VVIQ) (Marks, 1973)

Visual imagery refers to the ability to visualize, that is, the ability to form mental pictures, or to "see in the mind's eye". Marked individual differences have been found in the strength and clarity of reported visual imagery and these differences are of considerable psychological interest.

The aim of this test is to determine the vividness of your visual imagery. The items of the test will possibly bring certain images to your mind. You are asked to rate the vividness of each image by reference to the 5-point scale given below. For example, if your image is "vague and dim" then give it a rating of 4. After each item write the appropriate number in the box provided. Before you turn to the items, familiarize yourself with the different categories on the rating scale. Throughout the test, refer to the rating scale when judging the vividness of each image. Try to do each item separately, independent of how you may have done other items.

Please rate the vividness of each image by reference to the rating scale shown below:

1	2	3	4	5
Perfectly Clear and as vivid as normal vision	Clear and reasonably vivid	Moderately clear and vivid	Vague and dim	No image at all (only "knowing" that you are thinking of the object)

Think of some relative or friend whom you frequently see (but who is not with you at present), and consider carefully the picture that comes before your mind's eye. Then rate the following items:

1	The exact contour of face, head, shoulders, and body.
2	Characteristic poses of head, attitudes of body, etc.
3	The precise carriage, length of step, etc., in walking.
4	The different colors worn in some familiar clothes.

Visualize a rising sun. Consider carefully the picture that comes before your mind's eye. Then rate the following items.

5	The sun is rising above the horizon into a hazy sky.
6	The sky clears and surrounds the sun with blueness.
7	Clouds. A storm blows up, with flashes of lightning.
8	A rainbow appears.

Think of the front of a shop to which you often go. Consider the picture that comes before your mind's eye. Then rate the following items.

9	The overall appearance of the shop from the opposite side of the road.
10	A window display including colors, shapes, and details of individual items for sale.
11	You are near the entrance. The color, shape, and details of the door.
12	You enter the shop and go to the counter. The counter assistant serves you. Money changes hands.

Finally, think of a country scene which involves trees, mountains and a lake. Consider the picture that comes before your mind's eye. Then rate the following items.

13	The contours of the landscape.
14	The color and shape of the trees.
15	The color and shape of the lake.
16	A strong wind blows on the trees and on the lake, causing waves.

Appendix E

Screening Questionnaires used for the TMS study:

- The TMS Study Suitability Questionnaire

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TMS Study Suitability Questionnaire

Participant Reference Number:

Questions

Answer "Yes" or "No" to the following questions by ticking the appropriate box.

1. Do you have epilepsy or have you ever had a convulsion or a seizure?

☐ Yes ☐ No

2. Have you ever had a fainting spell or syncope?

☐ Yes ☐ No If "yes", please describe on which occasion(s):

3. Have you ever had severe (i.e., followed by loss of consciousness) head trauma?

☐ Yes ☐ No

4. Do you have any hearing problems or ringing in your ears?

☐ Yes ☐ No

5. Are you pregnant or is there any chance you might be?

☐ Yes ☐ No

6. Do you have metal in the brain/skull (except titanium)? (e.g., splinters, fragments, clips, etc.)

☐ Yes ☐ No

7. Do you have cochlear implants?

☐ Yes ☐ No

8. Do you have an implanted neurostimulator (e.g., DBS, epidural/subdural, VNS)?

☐ Yes ☐ No

9. Do you have cardiac pacemaker or intracardiac lines or metal in your body?

☐ Yes ☐ No

10. Do you have a medication infusion device?

☐ Yes ☐ No

11. Are you taking any medication, other than oral contraceptives?

☐ Yes ☐ No If “yes”, please list:

____

____

12. Did you have surgical procedures to your spinal cord?

☐ Yes ☐ No

13. Do you have spinal or ventricular derivations?

☐ Yes ☐ No

14. Did you ever undergo TMS in the past?

☐ Yes ☐ No

15. Did you ever undergo MRI in the past?

☐ Yes ☐ No

16. Do you suffer from claustrophobia?

☐ Yes ☐ No

- The Depression Anxiety Stress Scale (DASS) questionnaire (Psychology Foundation of Australia, 2013)

DASS

Participant *Date:*

Please read each statement and circle a number 0, 1, 2 or 3 which indicates how much the statement applied to you *over the past week*. There are no right or wrong answers. Do not spend too much time on any statement.

The rating scale is as follows:

0 Did not apply to me at all
1 Applied to me to some degree, or some of the time
2 Applied to me to a considerable degree, or a good part of time
3 Applied to me very much, or most of the time

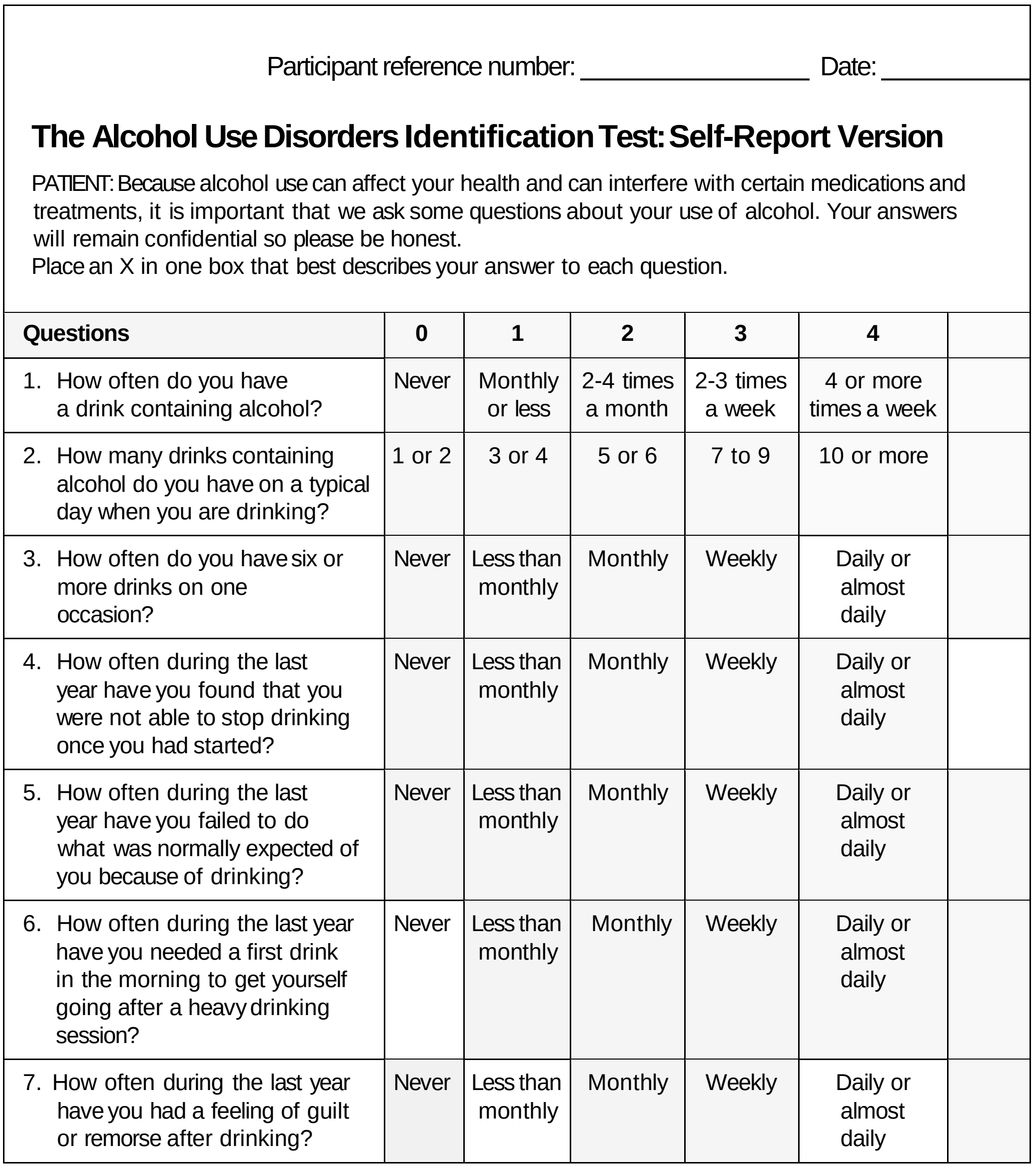
1	I found myself getting upset by quite trivial things	0	1	2	3
2	I was aware of dryness of my mouth	0	1	2	3
3	I couldn't seem to experience any positive feeling at all	0	1	2	3
4	I experienced breathing difficulty (eg, excessively breathlessness in the absence of physical exertion)	0	1	2	3
5	I just couldn't seem to get going	0	1	2	3
6	I tended to over-react to situations	0	1	2	3
7	I had a feeling of shakiness (eg, legs going to give way)	0	1	2	3
8	I found it difficult to relax	0	1	2	3
9	I found myself in situations that made me so anxious relieved when they ended	0	1	2	3
10	I felt that I had nothing to look forward to	0	1	2	3
11	I found myself getting upset rather easily	0	1	2	3
12	I felt that I was using a lot of nervous energy	0	1	2	3
13	I felt sad and depressed	0	1	2	3
14	I found myself getting impatient when I was delayed (eg, lifts, traffic lights, being kept waiting)	0	1	2	3

15	I had a feeling of faintness	0	1	2	3
16	I felt that I had lost interest in just about everything	0	1	2	3
17	I felt I wasn't worth much as a person	0	1	2	3
18	I felt that I was rather touchy	0	1	2	3
19	I perspired noticeably (e.g., hands sweaty) in the temperatures or physical exertion	0	1	2	3
20	I felt scared without any good reason	0	1	2	3
21	I felt that life wasn't worthwhile	0	1	2	3

22	I found it hard to wind down	0	1	2	3
23	I had difficulty in swallowing	0	1	2	3
24	I couldn't seem to get any enjoyment out of the things I did	0	1	2	3
25	I was aware of the action of my heart in the absence exertion (eg, sense of heart rate increase, heart missing a beat)	0	1	2	3
26	I felt down-hearted and blue	0	1	2	3
27	I found that I was very irritable	0	1	2	3
28	I felt I was close to panic	0	1	2	3
29	I found it hard to calm down after something upset me	0	1	2	3
30	I feared that I would be "thrown" by some trivial but unfamiliar task	0	1	2	3
31	I was unable to become enthusiastic about anything	0	1	2	3
32	I found it difficult to tolerate interruptions to what I was doing	0	1	2	3
33	I was in a state of nervous tension	0	1	2	3
34	I felt I was pretty worthless	0	1	2	3
35	I was intolerant of anything that kept me from getting on with what I was doing	0	1	2	3
36	I felt terrified	0	1	2	3
37	I could see nothing in the future to be hopeful about	0	1	2	3
38	I felt that life was meaningless	0	1	2	3

39	I found myself getting agitated	0	1	2	3
40	I was worried about situations in which I might panic and make a fool of myself	0	1	2	3
41	I experienced trembling (eg, in the hands)	0	1	2	3
42	I found it difficult to work up the initiative to do things	0	1	2	3

- The Alcohol Use Disorders Identification Test (AUDIT) (World Health Organization, 2001)



Participant reference number: ________________ Date: __________

The Alcohol Use Disorders Identification Test: Self-Report Version

PATIENT: Because alcohol use can affect your health and can interfere with certain medications and treatments, it is important that we ask some questions about your use of alcohol. Your answers will remain confidential so please be honest.
Place an X in one box that best describes your answer to each question.

Questions	0	1	2	3	4	
1. How often do you have a drink containing alcohol?	Never	Monthly or less	2-4 times a month	2-3 times a week	4 or more times a week	
2. How many drinks containing alcohol do you have on a typical day when you are drinking?	1 or 2	3 or 4	5 or 6	7 to 9	10 or more	
3. How often do you have six or more drinks on one occasion?	Never	Less than monthly	Monthly	Weekly	Daily or almost daily	
4. How often during the last year have you found that you were not able to stop drinking once you had started?	Never	Less than monthly	Monthly	Weekly	Daily or almost daily	
5. How often during the last year have you failed to do what was normally expected of you because of drinking?	Never	Less than monthly	Monthly	Weekly	Daily or almost daily	
6. How often during the last year have you needed a first drink in the morning to get yourself going after a heavy drinking session?	Never	Less than monthly	Monthly	Weekly	Daily or almost daily	
7. How often during the last year have you had a feeling of guilt or remorse after drinking?	Never	Less than monthly	Monthly	Weekly	Daily or almost daily	

8. How often during the last year have you been unable to remember what happened the night before because of your drinking?	Never	Less than monthly	Monthly	Weekly	Daily or almost daily	
9. Have you or someone else been injured because of your drinking?	No		Yes, but not in the last year		Yes, during the last year	
10. Has a relative, friend, doctor, or other health care worker been concerned about your drinking or suggested you cut down?	No		Yes, but not in the last year		Yes, during the last year	
					Total	

Appendix F

TMS Adverse Effects Questionnaire used in experiment 7:

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Adverse Effects Questionnaire

Questions

1. Please answer the following mathematical question:
   How many times does **5** go completely into **162** and what is the reminder?

2. Please answer the following general knowledge question: Name 2 cities in Germany:

A flock is to birds as a pack is to...

Please turn over for the final question

3. Please complete the table for the following symptoms:

Symptom:	Is it present? 0 - Absent 1 - Mildly 2 - Moderately 3 - Severely	If present, is it related to TMS? 0 - No 1 - Remotely 2 - Possibly 3 - Probably 4 - Yes	Notes:
Headache			
Neck pain			
Scalp pain			
Tingling			
Itching			
Burning sensation			
Skin redness			
Sleepiness			
Trouble concentrating			
Acute mood change			
Other (please specify)			

Appendix G

Supplemental Data (Chapter 2)

Time Course Analysis on Experiments 1, 2, and 3

In order to compare the time course of the micro-affordance effects observed in experiments 1, 2, and 3, a further general analysis was carried out on the response time data from each experiment.

The procedure for the analysis involved dividing participants' response times into 'grasp compatible' and 'grasp incompatible' trials, and then rank ordering them. The rank ordered RTs were then divided into five 'bins', averaged and then entered into a three-way mixed analysis of variance with Compatibility (compatible, incompatible trials) and Bin (five levels) as within participants factors, and Presentation Mode (object pictures, object written names, object spoken names) as a between participants factor. The difference between 'compatible' and 'incompatible' bin averages was taken as a reflection of the effect size at the different response latencies. The results of this analysis are displayed below in Figure G 1

.

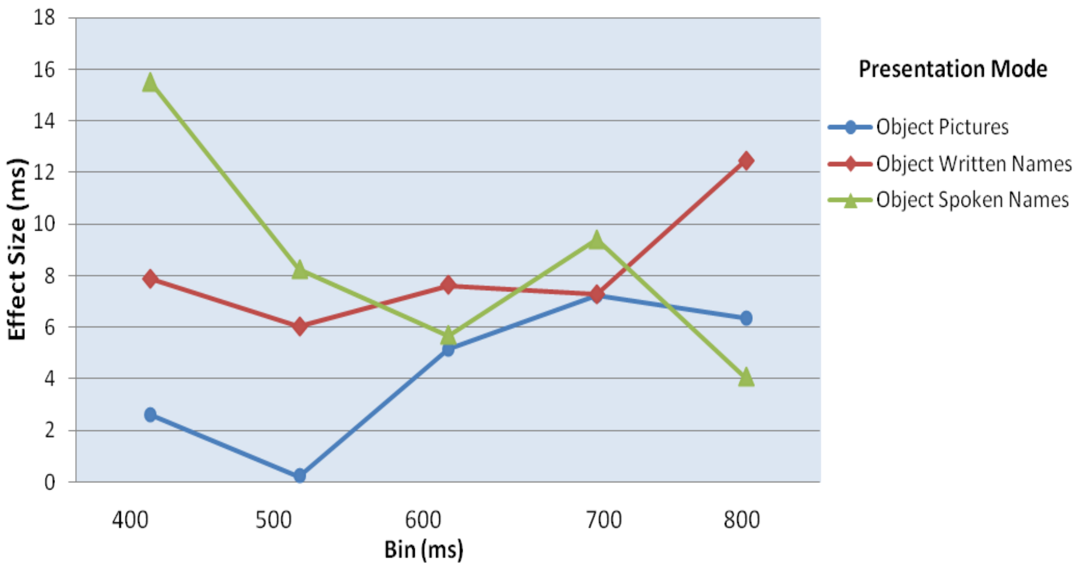

Figure G 1. Time Course Analysis to compare the effect size over time between Experiments 1, 2, and 3.

The results showed a significant main effect of Presentation Mode, with participants categorizing object pictures (M = 514.56; Se = 10.23) 77 ms faster than object written names (M = 591.67; Se = 10.69), and 285 ms faster than object spoken names (M = 799.90; Se = 10.23) [F (2,67) = 577.526; p = .000 η_p^2 = .945].

In addition, a significant main effect of Bin [F (1.5, 103.3) = 5113.497; p = .000 η_p^2 = .987] and a significant interaction between this factor and Presentation Mode [F (3.08, 103.3) = 53.469 p = .000 η_p^2 = .615] were found.

Averaged over the experiments, the compatibility effect was highly significant. Compared to incompatible trials, Rts for compatible trials were on average 7.054 ms faster (4.42 ms in experiment 1, 7.92 ms in experiment 2, and 8.81 ms in experiment 3) [F (1,67) = 43.668; p = .000 η_p^2 = .395].

No two-way interaction between Compatibility and Presentation Mode was observed, which suggests that the compatibility effects obtained did not differ significantly between the three experiments [F (2,67) = .929; p = .400].

Additionally, the absence of a significant three-way interaction between Compatibility, Bin and Presentation Mode [F (3.6, 121.2) = 1.607; p = .182] suggests that the compatibility effects emerged in all the experiments follow a similar temporal evolution.

Appendix H

Supplemental Data (Chapter 2)

General Analyses by Items

In addition to analysing the data obtained in each experiment by subjects, they were analysed by items as well.

This section reports the results of two general analyses by items carried out on both the response time data and error data from experiments 1, 2, and 3.

Participants responses (both mean Rts and mean percentage error rates) were entered into three way mixed analyses of variance with Graspability (pinchable, graspable), Response (precision, power) as within items factors, and Presentation Mode (object pictures, object written names, object spoken names) as a between items factor.

The results showed a significant main effect of Presentation Mode in the response time data. Object pictures (M = 515.35; Se = 3.90) were responded to 76 ms faster than object written names (M = 591.12; Se = 3.90), and 283 ms faster than object spoken names (M = 798.47; Se = 3.90) [F (2,273) = 1412.158; p = .000 η_P^2 = .912].

A main effect of Presentation Mode was observed even in the error data [F (2,273) = 4.404; p = .013 η_P^2 = .031]. Fewer errors were observed for object spoken names (M = 2.02%; Se = .210) than for object written names (M = 2.41%; Se = .210) and object pictures (M = 2.90%; Se = .210).

Averaged over the experiments, the Graspability by Response compatibility effect was significant for both measures of performance. Compared to incompatible trials, Rts for compatible trials were on average 7.31 ms faster (4.96 ms in experiment 1, 7.94 ms in experiment 2, and 9.02 ms in experiment 3) [F (1,273) = 13.863; p = .000 η_P^2 = .048], and produced .86% fewer errors (.93% in experiment 1, .81% in experiment 2, and .83% in experiment 3) [F(1,273) = 17.090; p = .000 η_P^2 = .059].

Finally, no three way interaction between Graspability, Response and Presentation Mode factors was observed: the compatibility effect obtained did not differ significantly between the three experiments for both Rts [F (2,273) = .381; p = .683], and Errors [F (2,273) = .033; p = .967].

As can be seen from figure H 1, in the analyses by items a pattern of results analogous to that emerged in the analyses by subjects was observed.

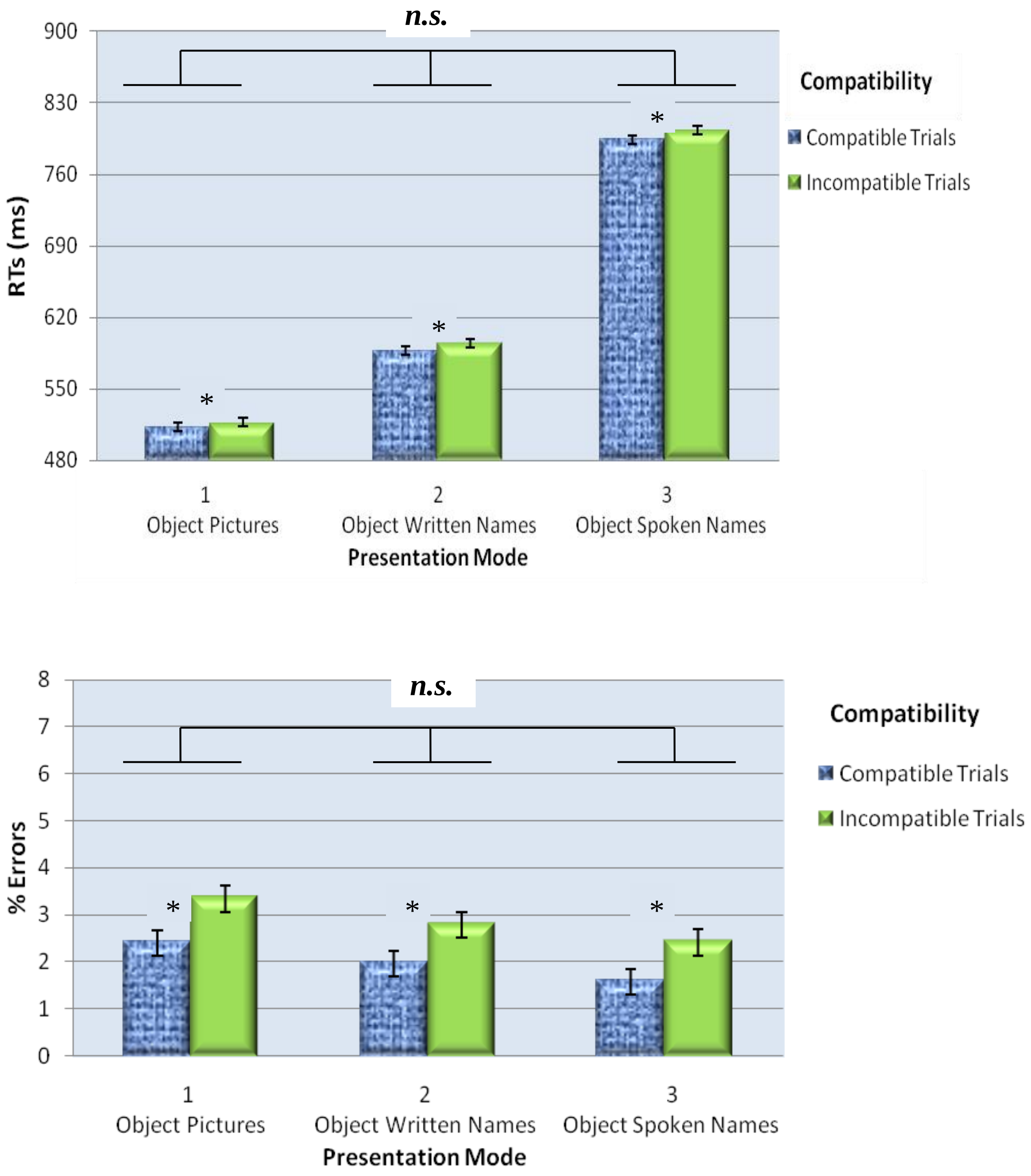

Figure H 1.
Mean Response Times (top) and Mean Percentages of Errors (bottom) for Compatible and Incompatible Trials in Experiments 1, 2, and 3.
Error bars denote standard errors.