

UNCONSCIOUS PRIMING OF "FREELY"
CHOSEN VOLUNTARY ACTIONS: BEHAVIORAL
AND ELECTROPHYSIOLOGICAL EVIDENCE

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Chapter 1

Introduction

In everyday life we usually act to achieve a desired goal. For instance, we switch on the light to illuminate a room. In order to act goal-oriented one has to know in advance which actions are necessary to achieve the desired goal. In other words, the actor has to have a mental representation of the intended effects or goals before moving. If we assume that a mental representation precedes goal-directed, or voluntary, actions interesting questions arise. How are these effect representations acquired? How does our cognitive system *know* which action causes which effect? How can mental representations of the action-effects be used to control or guide our movements? The aim of this thesis is to provide empirical evidence and theoretical insights concerning the question of *how* actions are controlled specifically focussing on the role of unconscious action-effects in action planning and control. Behavioral as well as electrophysiological measures are used mostly in combination with subliminal priming paradigms to investigate this issue. Chapter 2 provides an overview over theoretical approaches and important empirical findings concerning action control mechanisms. It also provides theoretical information about the experimental paradigm (visual masking) and electrophysiological measures (in particular, the lateralized readiness potential derived from the electroencephalogram) used in this dissertation. Thereafter, in chapter 3, own studies using behavioral and electrophysiological measures are described. The experiments aim to clarify and complement established knowledge about the role of action-effects in action control. Specifically, the influence of unconsciously presented action-effect features on response activation and selection processes was investigated. Furthermore, action-effects with different emotional valences were

used to study whether emotional features of action-effects become integrated into action representations and whether they influence response selection differently. In chapter 4 the obtained results are discussed and integrated into a more general theoretical view of action control mechanisms and the free will debate.

The fact that in all my experiments participants performed simple key-pressing actions makes it necessary to briefly justify why I consider these actions to be suited to investigate general action control or planning processes. Any voluntary action can be defined as goal-directed behavior (e.g., Hommel, 2003; Prinz, 2000). They are directed towards a particular anticipated goal and play a causal role in fulfilling that goal (i.e., attaining intended effects). As noted above, to perform a goal-directed (voluntary) action one has to have a mental representation of the desired goal or intended effect. Anticipated sensory consequences of actions (i.e., action-effects) can be twofold: First, they can refer to movements of one's own effectors (e.g., the perceived feedback of muscles joints etc.), or, second, they can refer to remote (visual or auditory) changes in the outside world. According to James (1890) the anticipation of both types of action-effects can be equally used to initiate actions. Thus, according to the above definition of voluntary action, even key-presses - despite their simplicity - are voluntary actions which are performed to produce an intended effect. The proximate action-effect, in this case, is the perception of the feeling of the finger pressing down the key, whereas, more remote effects may concern changes in the surrounding of the observer (e.g., that a light turns on or the participant communicates a specific judgement in accordance with the prior experimental instructions). But are these simple key-press actions really comparable to the much more complex actions we usually produce in everyday life? Everyday goals often refer to the distant future and are usually not achieved by performing only one simple action. To achieve long-term goals, sequences of actions have to be performed and hierarchically organized sub-goal structures must be processed. One example is driving to work by car. The final goal might be getting to work but to achieve this one has to realize several sub-goals like turning right at the appropriate corner or shifting gears. Complex action planning thus can be decomposed into the planning of simpler sub-actions, each of which is structurally equal in that it is directed at achieving a particular sub-goal. Therefore, it seems justified to study simple key-press actions in the laboratory to acquire knowledge about action control processes as it is the case in the experiments conducted in this dissertation.

Chapter 2

Theoretical background

2.1 Theories of action control

Two major theoretical approaches about what actions are and how they are controlled can be distinguished: Sensorimotor and ideomotor theories. The sensorimotor view assumes that actions are triggered by external causes or stimuli, whereas the ideomotor principle (IMP) views actions as results of internal causes like goals or intentions. The following sections describe these two theoretical lines in more detail.

2.1.1 Sensorimotor mapping

The sensorimotor view states that actions are "re-actions", meaning that they are triggered by external cues ('stimulus trigger hypothesis'). The idea is, that actions are initiated once appropriate triggering conditions have been perceived, as, for instance, when one stops the car when seeing a red traffic light. Historically, this view dates back to one of Descartes' (1664) assumptions that actions are the result of the perceived events (e.g., his notion of an reflexive arc). More recently, behavioristic as well as more cognitive oriented research like serial information processing theories (Neisser, 1967; Donders, 1862) were influenced by this view. By sensorimotor mapping, people acquire associations between cueing stimuli (S) and subsequent actions or responses (R) (e.g., they learn under which external circumstances it is appropriate to carry out an action). It is likely that this acquisition process relies on associative learning mechanisms integrating events that frequently occur

in close temporal succession. One function of sensorimotor mapping in everyday life is the adaptation of behavior to the environment by allowing quick changes in behavior in reaction to environmental changes. For instance, when driving a car, perceiving the red traffic light allows one to appropriately adjust behavior by stepping on the brake. In the laboratory, questions concerning sensorimotor theories are investigated with tasks which include well-defined sets of stimuli and responses (as for instance in instrumental conditioning, paired-associate learning, or forced-choice reaction tasks). In these paradigms the task instructions specify which stimuli can occur, which responses can be selected, and which rules govern the mapping of responses to stimuli (Sanders, 1980, 1998; Toni & Passingham, 1999; Wise & Murray, 2000). For instance, a typical instruction could be to press the left key whenever a red square appears and a right key whenever a green square appears. In such a case the stimulus (e.g., red square) is associated with the response (e.g., left) and the subsequent perception of the stimulus is thought to trigger the corresponding response. Questions investigated in the context of sensorimotor theories are how associations between sensory cues and subsequent actions are acquired and how S-R relations are represented internally. Of further interest is the question of which factors determine the strength of these S-R associations and how one can separate processing stages and operations by which stimulus information is translated into motor commands.

Although sensorimotor theories of action have been very successful they clearly do not capture all processes involved in action control. Specifically, they disregard one of the most important features of voluntary actions: Their guidance by intentions or goals (Hommel, Müsseler, Aschersleben, & Prinz, 2001). This additional feature is accounted for in ideomotor views of action control.

2.1.2 The ideomotor principle (IMP)

To perform an intentional, goal-directed action, the agent needs to know what consequences a particular movement will have. Therefore, voluntary actions not only depend on the ability to extract appropriate action "triggering" stimuli but also on the ability to learn associations between movements and their perceivable consequences. The ideomotor principle (IMP) relates actions to their contingent sensory effects. It describes how action is guided by perception and imagery. Unlike in the sensorimotor view where external

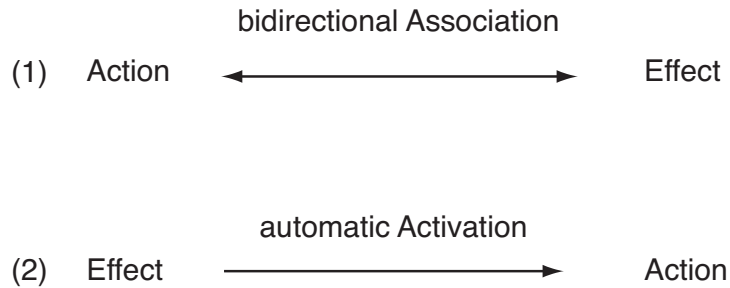


Figure 2.1: **Two processes involved in action control according to the ideomotor view.** (1) First, randomly generated movements lead to specific changes in the environment (effects). The motor pattern of the action is then associated with its effect in a bidirectional fashion. (2) Once action-effect associations have been acquired, action control is based on the fact that actions are automatically activated by anticipating their consequences (effects).

cues are associated with responses, by ideomotor learning, associations between actions (responses; R) and subsequent sensory events (i.e., action-effects; E) are acquired (R-E relations). The importance of ideomotor learning is obvious: Without learning associations between actions and their consequences, we would be unable to plan a movement that is appropriate to achieve a desired action-effect (i.e., a *goal*). As mentioned above, action-effects can be *any* internal or external changes following a movement. The idea is that whenever an action is carried out and an effect (change) is registered the action and the effect are linked together (i.e., associated). This is illustrated in Figure 2.1.

Associations between actions and their subsequent effects are assumed to be bidirectional. Therefore, not only does performing an action lead to the anticipation of its sensory effect, but the converse is also true: anticipating an action-effect triggers the action that usually brings about this effect. Thus, the IMP states that whenever a person performs a voluntary action, this action has been triggered by the anticipation of the intended effects. One example, which illustrates how the IMP and sensorimotor mapping differ is stopping a car at a red traffic light. According to the sensorimotor view the driver stops the car because the "red" is signaling him to "stop" and the perception of this signal leads to the selection of the braking action. In contrast, according to the ideomotor view he stops the car because he wants to avoid an accident. He therefore desires to stop the car and anticipating that goal leads to the recruitment of the appropriate action.

Although the term "ideomotor" was introduced by Carpenter (1852) and the ideomotor principle mostly popularized by William James (1890) in his famous book "Princi-

ples of psychology”, one of the earliest theoretical assumptions of how voluntary actions may be controlled from the perspective of an ideomotor view stems from the philosopher Lotze. Lotze (1852) observed that when a motion is perceived (e.g., throwing of a ball), the perception is often accompanied by small body movements (e.g., of an arm) suggesting that humans tend to imitate or copy perceived actions (“Nachahmungsbewegungen”; Prinz, 1987; Hoffmann, 1993). This observation led Lotze to assume that mental representations of movements are powerful enough to induce corresponding motor patterns in the perceiver. Lotze (1852) was also one of the first to propose that voluntary actions are based on an associative learning process starting shortly after birth. He assumed that the “soul” registers sensory changes following movements, and that connections between these changes and the movements which caused them are established. After relationships between actions and effects have been learned, merely thinking of a desired effect will automatically lead to the execution of the appropriate body movements. Harless (1861) specified in more details how movement-related knowledge is acquired and used later on. Like Lotze, he assumed that the associations between a motor code (m) and a sensory code (s) are essential for voluntary actions. If one wants to perform an action to attain a desired effect one makes intentional, goal-directed use of learned knowledge about m-s associations to recruit appropriate movements. Since the associations are assumed to be bidirectional, re-activating (i.e., anticipating by perceiving, imagining, or thinking of) the representation of a particular action-effect (s) results in the automatic activation of the associated movement pattern (m). The ideas by Lotze (1852) and Harless (1861) were adopted by William James (1890). Including their contributions along with concepts brought forward by others (e.g., Carpenter, 1852) in his classic textbook “Principles of psychology” ensured the spreading of the ideomotor idea (Stock & Stock, 2004). Of course, the ideas by Lotze, Harless and others were very general and not tested experimentally. More recently, however, the theoretical framework underlying the IMP has been developed further, leading to specific and testable assumptions of how action-effects control our actions, both simple and more complex ones (Elsner & Hommel, 2001; Hoffmann, 1993; Hommel, 2003; Hommel et al., 2001; Prinz, 1997).

2.1.3 The acquisition and control of actions: A two-stage model

Recently, a more specific theoretical and experimental approach was taken by Elsner and Hommel (2001) to solve the question of how action-effect representations are acquired and how they are used to control our actions. Following ideas by Lotze and Harless, these authors propose that voluntary actions are acquired via a two-stage associative learning process. In a first stage relationships between movements and their consequences (effects) are perceived/encoded. This experience leads to an automatic integration of the cognitive codes of the movement (motor codes, response codes) and the codes of the effect (sensory feature codes). In a second stage these learned movement-effect associations are now used to guide or control actions. If one wants to attain a desired effect a mental representation of this effect is produced by the cognitive system via effect anticipation (by perceiving, imagining or thinking of the effect). The effect-anticipation leads to the activation of the movement pattern associated with this effect. The following section describes this two-stage model of action control in more detail.

The acquisition of movement-effect relations

The first stage of the model proposed by Elsner and Hommel (2001) is the automatic acquisition of response-effect (R-E) associations or, in other words, of contingencies between movements and effects. In this stage codes of movements and their perceived consequences (action-effects) are linked in a bidirectional fashion. Knowledge about action-effect relations is essential for performing goal-oriented actions. Figure 2.2 presents a gross model of how the acquisition of R-E associations is thought to operate. First, a randomly generated motor pattern is set up and a movement is carried out. The movement results in a particular effect (that is, a perceivable internal or external change). The registration of these changes leads to a certain pattern of activation in the cognitive system. If a motor and sensory pattern are experienced together several times, an association between the action and its effects is formed via simple learning mechanisms. As a consequence, the feature codes of the movement and its sensory effect are automatically integrated into a representation of this action.

As an example consider a baby moving its arms in a random fashion. On some occasions the baby might hit a bell hanging above his head. The bell produces a sound and

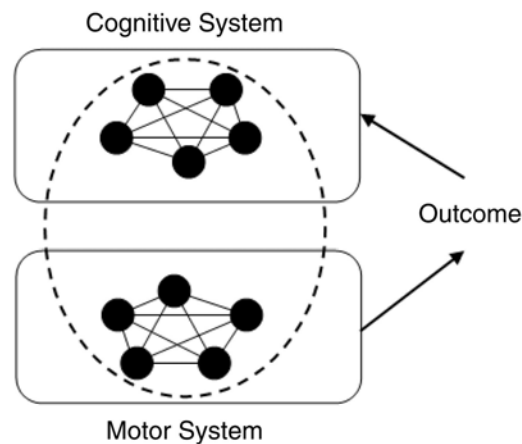


Figure 2.2: **Stage 1 of the two-stage model of the emergence of action control.** A motor pattern produces a certain effect and is automatically integrated with the cognitive (sensory) codes representing this effect (adapted from Elsner & Hommel, 2001).

swings (the effects) and this is registered by the baby’s cognitive system. If this accidental hitting of the bell occurs several times, the specific motor pattern of the arm movement (the action code) is associated with the sensory codes of the effects, that is, the sound of the bell (auditory effect) and its swinging (visual effect). Besides motor and effect feature codes (visual, tactile, auditory)¹, action representations must also contain information about the context in which the action is carried out (Hoffmann, 1993). In summary, the first stage of the two-stage model is an associative learning process which links movements to their perceivable consequences. As will be shown in the next section, these bidirectional R-E associations are a necessary requirement for action planning processes.

The planning and selection of actions

The second stage of the model represents the actual action control process. It explains how movements are selected by activating perceptual codes that represent a desired goal or action-effect. Action planning or control can thus also be seen as a binding process that integrates codes of the features that the intended action should have. As described

¹It is likely that not only directly perceivable but also subjective effect feature codes can become part of the cognitive representation of an action (e.g., Beckers, De Houwer, & Eelen, 2002; see 2.2, page 12 for details).

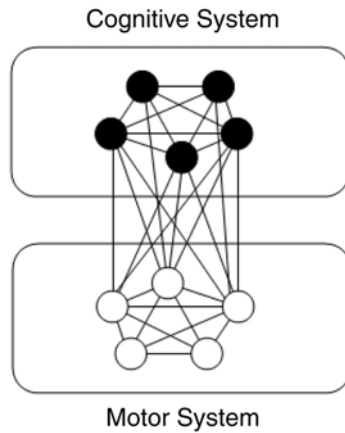


Figure 2.3: **Stage 2 of the two-stage model of action control.** Movements are recruited by activating the cognitive codes representing desired outcomes (action-effects)(adapted from Elsner & Hommel, 2001).

above, experiencing contingencies between actions and sensory events leads to the formation of bidirectional links between the motor codes of that action and the codes of the accompanying effects. This bidirectional linkage is essential for action planning because it makes it possible that actions can be primed, retrieved, and launched by activating (mentally represented) features of their effects (Elsner & Hommel, 2001; see Figure 2.3). This activation can happen intentionally or incidentally by stimuli that share features with the action-effects. Activating an effect code will tend to activate its associated motor pattern (i.e., motor code) to a certain degree. It is this activation, which allows the effect-oriented selection of actions. The spreading of activation from the effect feature codes to the motor codes is thought to happen automatically (independently of the actor's intentions). Nevertheless, additional intentional processes play an important role in action control by endogenously activating effect representations, which then automatically trigger associated motor codes. If the baby from the example given above wants to hear the sound of the bell again, it may "think of" or imagine the sound. This thought or image will activate the auditory effect code, which will - if sufficiently strong - lead to an automatic spreading of activation to the associated motor codes.

More specifically, Elsner and Hommel (in press) assume three phases involved in action planning: an activation-phase, an integration-phase, and an implementation-phase.

During the *activation-phase* the features of the to-be executed action are specified. This is achieved by activating feature codes representing the sensory effects of the intended action. Importantly, not all feature codes of the effect have to be activated. The idea is that activating only one feature is often sufficient to elicit a spreading of activation to the other elements of the action representation. The activation of feature codes can be triggered by internal sources (imagining) or by external sources in the environment (contextual information). Importantly, the activation of the feature codes leads to an automatic activation of the motor codes associated with these features which can influence response selection, response initiation and response execution (Hommel, in press; Kunde, Koch, & Hoffmann, 2004). Of course, this response priming does not automatically lead to the execution of the action represented by the motor codes. If this would be the case, we would carry out inappropriate actions all the time which are unwillingly triggered by external stimuli ². During the second phase, the *integration-phase*, all activated feature codes belonging to the intended action are integrated and temporarily bound into an action plan. One problem, that is associated with the integration of feature codes is how our cognitive system "knows" which motor codes and which effect codes belong to which action plan? This problem arise when we pursue not only one, but several action plans at the same time (Hommel, in press). Often, prepared action plans overlap temporarily, as when we do different things simultaneously like talking while riding a bike. How does the activation of an effect code lead to the automatic activation of the correct motor code? How are the elements belonging to an action plan bound together in the brain ³? These questions refer to the so-called "binding problem". The most likely solution is that cortically distributed elements of an action plan are integrated by coordinating their temporal properties (Hommel, in press). All elements belonging to one action plan receive

²An unavoidable immediate execution of the primed action can be seen in patients with bilateral frontal lobe lesions who show so-called 'utilization behavior'. They for instance grasp objects, like a tooth-brush, and use it although doing so is inappropriate (Lhermitte, 1983).

³Recent findings based on functional magnetic resonance imaging (fMRI), positron emission tomography (PET), and single cell recordings in monkeys provided evidence that a network of neurons, distributed over distant brain areas is involved in action planning and that information processing is realized in a parallel fashion. These brain areas include primary motor cortex (M1; area 4), the pre-motor cortex (PMC), the supplementary motor area (SMA), the frontal-eye-fields (FEF), and the posterior parietal cortex (area 5, area 7) as well as parts of the dorsolateral prefrontal cortex and parts of the posterior cingulate (area 24). The sub-cortical areas include the cerebellum and the basal ganglia (Dettmars, Fink, Lemon, Stephan, Passingham, Sibersweig, Holmes, Ridding, Brooks, & Frackowiak, 1995; Gazzaniga, Ivry, & Mangun, 2002; Requin, Lecas, & Vitton, 1990; Requin, 1992; Rizzolatti, Luppino, & Matelli, 1998).

a "tag", by which they can identify each other and thus be bound together. Such a tag could consist in the temporal pattern of neural activity, in particular the firing of neurons or assemblies of neurons belonging to the same action plan (Hommel, in press; Singer, 1994; von der Malsburg, 1995). Many studies within the field of visual feature binding have suggested that temporal synchronization is a plausible candidate for functionally linking neurons within and between cortical areas and subcortical structures (Singer, 1994; Basar-Eroglu, Strüber, Schürmann, Stadler, & Basar, 1996 for review). Recent studies have provided evidence for the role of synchronization in action control as well (Pfurtscheller, Flotzinger, & Neuper, 1994; Salenius, Salmelin, Neuper, Pfurtscheller, & Hari, 1996). For the time during which an action plan is activated, the feature codes belonging to it are less available for planning other actions involving the same features (Stoet & Hommel, 1999). However, after the action has been executed this feature binding decays and the feature codes are again available for other planning activities.

The automatic activation of motor codes by the activation of feature codes and their integration into a coherent action plan takes place during the activation- and integration-phase. As noted above, in these stages, only partial response activation is achieved which does not necessarily (or usually) lead to the execution of the action. The actual implementation of the action plan takes place in the third step - the *implementation-phase*. If an action plan is sufficiently prepared (i.e., an action plan is set up and the action is ready to be carried out) information between planning structures and the motor system is released, and the action can be executed (Elsner & Hommel, in press). The planning of an action (i.e., the activation and integration of feature codes) and its implementation seem to be functionally and temporally independent from each other (De Jong, 1993; Elsner & Hommel, in press; Sommer, Leuthold, Abdel-Rahman & Pfütze, 1997).

In summary, the elaborated two-stage model explains how, in accordance with the ideomotor principle, actions are selected by anticipating (i.e., by activating the codes of) their consequences. A novel feature of this account is that actions are cognitively represented in a distributed fashion (in terms of their features). Action plans are interconnected bundles of action feature representations (e.g., effect codes, motor codes, context codes). Activation of only a few feature codes belonging to an integrated action representation will tend to activate the whole action representation, including its motor part. This means,

that not all possible effects or all features of a given effect have to be anticipated or perceived to activate the action representation. However, the more features are activated, the greater is the activation of the motor pattern. This increases the likelihood of actually selecting and executing the associated action (Hommel, 2003).

2.2 Empirical findings on the role of effect anticipation in action control

Over the past decades numerous empirical studies have been conducted concerning the role of action-effects in action control. The next section will review empirical findings concerning action control processes, in particular the ideomotor principle, which are relevant for the experiments conducted in this thesis. Because of the huge amount of research conducted in the field of action control this review is restricted to experiments investigating the control of very simple actions. Research on more complex actions or general theories of motivation and volition will not be discussed (e.g., Gollwitzer & Bargh, 1996; Gollwitzer, 1990, 1993; Lewin, 1926; Mischel, 1996). Although the latter theories may appear more transferable to everyday actions, it should be noted that more complex everyday actions are composed out of simpler elements, which are organized in a hierarchical and sequential manner (Carver & Scheier, 1990; Hacker, 1998; Miller, Galanter & Pribram, 1960). For instance, the complex action of writing a Phd thesis can be decomposed into simpler actions like reading articles, analyzing data, writing chapters, which in turn are composed out of even simpler actions (e.g., writing a sentence), which ultimately consist of simple responses (e.g., typing a particular letter). Thus studying action control processes in seemingly artificial experiments using simple actions in the laboratory does not mean that the processes under investigation are not also operative in the execution of more complex actions.

One early experimental approach to the ideomotor principle was taken by Greenwald (1970a,b). Greenwald (1970a,b) was one of the first who proposed to associate actions with additional sensory effects via a learning process within an experimental setting to test whether these novel effects can activate their associated actions if presented later on. A more recent approach to empirically test the ideomotor principle and the role of intended

action-effects in action control was taken by Hommel (1996). His experiments consisted of two phases - an acquisition-phase and a test-phase. During the acquisition-phase the task was to press a particular key as fast as possible in reaction to a particular visual stimulus (e.g., O > left key-press; X > right key-press). Contingent on the key-press a tone was presented as the action-effect (e.g., left key-press > high tone; right key-press > low tone). During the test-phase the visual stimuli (O or X) were presented again as targets and a key-press reaction was asked for. Shortly before or accompanying the imperative stimuli, the action-effect tones from the acquisition-phase were presented as primes. Depending on the combination of the prime - target pairs congruent (high tone - O, low tone - X) or incongruent (high tone - X, low tone - O) trials were realized. The results showed that response times (RTs) were shorter in the congruent than in the incongruent condition. This finding indicates that the repeated experience of a tone following a motor response (key-press) led to an automatic formation of a bilateral action-effect association in the acquisition-phase, which is in accordance with the two-stage model of action control. In the test-phase the presentation of the former effect-tone prior to the key-press led to some activation of the associated motor code, which speeded up response selection in the congruent condition, but slowed down performance in the incongruent condition.

Another series of experiments conducted by Elsner and Hommel (2001) is consistent with these conclusions. These authors showed that action-effect associations do not only affect the speed of response selection, but may also influence which action is selected. Again, there was an acquisition- and a test-phase. During the acquisition-phase free-choice key-presses had to be executed in response to a Go-signal (tone). The key-presses were followed by effect-tones which were contingent on the key-presses (e.g., left key-press > high tone; right key-press > low tone). During the test-phase the effect-tones were presented randomly and participants were asked to freely choose to press one of the keys known from the acquisition-phase. The results showed that the choices were not random, but rather depended systematically on the type of tone. If the tone previously delivered after a left key-press (the high tone) was presented it was more likely that the participants pressed the left key in reaction (acquisition-consistent choice) and vice versa. One possibility, which cannot be entirely ruled out, is that participants used a deliberate response strategy in the test-phase (e.g., "Whenever a high tone appears I will press the

right key”). If this would be the case, the influence of response priming by the action-effect stimuli would not become evident in the response choices because the intended, conscious strategy is much more stronger than the unconscious, automatic priming effect (at least in the majority of trials). One way to avoid conscious response strategies would be to use subliminal primes (e.g., stimuli which participants do not become aware of) as action-effect primes during the test-phase. Despite the possibility of conscious response strategies, the findings by Elsner and Hommel (2001) again indicate that bilateral associations between movements codes and their perceivable effects are formed automatically and - importantly - that action-effect representations play a crucial role in action planning. A study using positron emission tomography (PET) with a similar experimental design showed that the caudal supplementary motor area (SMA) and the right hippocampus were activated when participants merely perceived former action-effect tones (Elsner, Hommel, Mentschel, Drzezga, Prinz, Conrad, & Siebner, 2002). The increased activation in the SMA suggests that representations of motor actions are indeed automatically activated if features of their former effects are perceived. The activation of the hippocampus may relate to the retrieval of action-effects rules from episodic-memory. Furthermore, it has been shown that the pre-motor cortex is activated while watching a familiar, purposeful action but not when new, meaningless actions are observed (Decety, Grezes, Costes, Perani, Jeannerod, Procyk, Grassi, & Fazio, 1997), which is in accordance with the ideomotor view of action control. There is also neurophysiological evidence for the integration of observed (perceived) action codes. It has been shown that the same cells were active when a macaque monkey either performed a goal-directed action himself and when he watched an experimenter performing the action (Di Pellegrino, Fadiga, Fogassi, & Rizzolatti, 1992). Analogous results were obtained in humans with imaging techniques (Grafton, Arbib, Fadiga, & Rizzolatti, 1996; see Hommel, in press).

The finding that action-effects may prime actions with which they have been associated is not a modality specific phenomenon. It appears that many kinds of action-effect stimuli can become effective action-primes. The establishment of action-effect learning in the auditory domain using tones has been shown in numerous experiments across different laboratories (Elsner & Hommel, 2001; Elsner et al., 2002; Hoffmann, Sebald, & Stöcker, 2001; Hommel, 1996; Hommel & Elsner, 2001; Kunde, Hoffmann, & Zellman,

2002; Stöcker & Hoffmann, 2004). There is also evidence for the integration of actions and their consequences in the visual domain (Ansorge, 2002; Hommel, 1993; Ziessler, 1998; Ziessler & Nattkemper, 2001, 2002; Hommel, Alonsa, & Fuentes, 2003). It has been shown that action representations include information about very different kinds of action-effects (proximal and remote, immediate and delayed) (Hommel, 1997, 1998). Furthermore, the automatic acquisition of action-effects does not seem to be restricted to simple forced-choice tasks. With serial learning tasks (e.g., learning of complex sequences of key-presses) it has for instance been shown that sequence learning was much better and faster if the key-presses produced certain tones so that the subjects could integrate their responses with the tones and thus learned the 'melody' they produced (e.g., Sebald, Hoffmann, & Stöcker, 1999; see also Hoffmann et al., 2001; Stöcker & Hoffmann, 2004; Ziessler, 1998). The concept of ideomotor action can also be found in acquiring knowledge of how to act successfully in different situations (i.e., action competence; Hoffmann & Sebald, 2000; Stock & Hoffmann, 2002). In most situations it is not enough to know the consequences an action might have for the action to be useful. An action representation must contain some specification of the context conditions under which it should be carried out (Hoffmann, 1993). These context conditions are most likely acquired intentionally. For instance, if playing the piano sight-read (by notes), one has to learn at some point which note belongs to which key. The player sees a note (context), presses the corresponding key (action) and produces a particular tone (effect). After this intentional, conscious learning process, the playing action (pressing a key in response to a certain note to produce a certain tone) can be performed automatically (Neumann & Prinz, 1987; for similar ideas see Allport, 1980; Anderson, 1982).

The experiments reviewed so far suggest that the perception of previously experienced action-effects activate representations of the actions with which they had been associated. However, to obtain convincing support for the ideomotor principle, it is not sufficient to show that former action-effects influence response selection when perceived before response execution. What needs to be shown is that action-effects become anticipated and influence performance when the effect-stimulus is not presented and thus not perceived before response execution (Hommel, 1998; Kunde, 2001). Evidence for this assumption was for instance presented by Kunde (2001), who showed that forthcoming (i.e.,

anticipated) action-effects influence action selection in the same way as if these effects were already perceived prior to the action. A four-alternative choice response time task was applied. Each of two effect tones was mapped onto two responses (e.g., response1 (R1) - effect-tone1 (T1), R2 - T2, R3 - T1, R4 - T2). At the beginning of each trial a cue indicated which of the four responses was most likely to be carried out in that trial and could therefore be prepared. The results showed that RTs were shortest on trials where the cued response was indeed asked for, i.e., on trials which were correctly prepared. More importantly, in the other unprepared trials the performance depended on the action-effect tones. Although RTs were generally longer on unprepared trials as compared to correctly prepared trials, the slowing was reduced when the required response shared its effect-tone with the prepared response (e.g., when R1 was prepared and R3 had to be executed; both responses share the same effect-tone (T1)). Thereby it was demonstrated that preparing a response is accompanied by an activation of the associated action-effect code (e.g., preparing R1 activates T1). This activated effect code (T1) then also primes other responses linked to it (R3 in the example).

Recently, it has been shown that not only directly perceivable but also more subjective features of an action-effect become integrated into action representations. By using electrocutaneous action-effects, Beckers et al. (2002) showed that the emotional valence of action consequences has an influence on subsequent action selection. In the acquisition-phase of these experiments participants had to move a key up or down to characterize neutral words as nouns or verbs. One of the two responses was always followed by a mild electric shock (negative action-effect) whereas the other response did not have any effect (positive action-effect). In the test-phase the task was to rate the valence of words (negative or positive) by moving the same key up or down. They found that the response to negative words was faster with the response directions associated with the shock and positive words were responded to more quickly with the response not followed by a shock. This indicates that actions acquire the emotional valences of their consequences. Another interesting area of research is the ontogenetic development of the acquisition of action-effect associations and their use in action control. There is converging evidence that bilateral association between responses and their sensory effects can be acquired from birth on (Watson & Ramey, 1972; Rovee & Rovee, 1969). The development of action-planning

abilities (and the intentional use of knowledge about action-effect relations) on the other hand is slower and extends over a longer time period (e.g., Diamond, 1990; Diamond & Gilbert, 1989; Diamond & Taylor, 1996; Mischel & Mischel, 1983). Eenshuistra, Weidema, and Hommel (2004) showed that 4-5 and 7 year old children acquire response-effect associations automatically to an equal degree but that the younger children tend to forget the current action goal more frequently. As a consequence, their behavior is more strongly influenced by automatic, stimulus-triggered response tendencies.

A question, which has only recently been addressed, but which is of central interest in this dissertation, is whether effect-feature codes have to be consciously perceived in order to induce motor activation. Research from the field of motivational psychology suggests that goals can become activated without conscious awareness and then operate nonconsciously to guide behavior (Bargh, 1990; Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trötschel, 2001). In one of their experiments, Bargh et al. (2001) showed that unconscious priming of the goal to perform well caused participants to perform comparatively better on an intellectual task. Nonconsciously activated goals apparently caused the same attention to and processing of goal-relevant information like consciously activated ones which led the authors to the conclusion that it does not matter how a goal is activated - consciously or unconsciously. The same could be true for effect representations and their influence on response activation. First evidence that subliminally presented action-effects can activate associated response codes comes from Kunde (2004). During the acquisition-phase of these experiments, participants performed free-choice key-presses in reaction to a Go-signal. Contingent on the key-presses a visual action-effect appeared (e.g., left key-press > arrow down; right key-press > arrow up). The test-phase was a speeded forced-choice reaction task, where participants had to respond to newly defined targets (e.g., red square > left key-press; blue square > right key-press). Before each target one of the two action-effect arrows from the acquisition-phase was presented below the threshold of awareness as a prime. Two possible prime-target pairs result from this design: response-compatible trials (e.g., arrow down - red square; arrow up - blue square) or response-incompatible trials (e.g., arrow down - blue square; arrow up - red square). The results revealed that RTs were shorter on compatible trials than on incompatible trials indicating that the unconscious effect-primers activated their corresponding response codes, which facilitated the reaction

to the targets on compatible trials.

That unconsciously presented stimuli can in principle influence behavior has been shown in numerous forced-choice reaction tasks (e.g., Neumann & Klotz, 1994; Eimer & Schlaghecken, 1998; Dehaene, Naccache, Le Clec, Koechlin, Mueller, Dehaene-Lambertz, et al., 1998; Cheesman & Merikle, 1986). So-called subliminal priming effects are usually obtained with paradigms using visual masks to reduce the visibility of the stimulus such that it remains below the threshold of awareness. As this thesis focuses on unconsciously presented action-effects an overview over types of visual masking as well as results obtained with different subliminal priming paradigms is necessary. The next section aims to provide this overview.

2.3 Visual masking and subliminal priming

2.3.1 Types of masking

Visual masking is a process where the response to one stimulus (prime or target) is affected by the presentation of another stimulus (mask). Masking occurs when the visual system is given insufficient time to identify individual stimuli. This happens if two stimuli are delivered to observers in rapid succession. The assumption is that the percept of the two stimuli is temporally summed which makes it difficult to identify the individual structure of either stimulus. Behavioral as well as electrophysiological studies have shown that stimuli presented near or below the threshold of conscious awareness can nevertheless influence human behavior (for an overview see Enns & DiLollo, 2004). Three general types of masking can be separated based on the spatial relationship between the edges of the target and the mask: Pattern-masking, metacontrast-masking, and object-substitution-masking. If the contours of target and mask are spatially superimposed the masking is referred to as *pattern-masking*. Pattern-masking can affect different stages of processing depending on the physical appearance of the masks used and the stimulus-onset-asynchrony (SOA; interval between the onset of the target and the onset of the mask). It can either produce integration- or interruption-masking. *Integration-masking* occurs when the representations of the target and mask are integrated. This happens under conditions where the target and the mask are perceived as belonging to one and the same pattern due to in-

sufficient temporal resolution of the visual system. Thereby, the target becomes difficult to identify, contrast is reduced, and masking is produced (i.e., Kinsbourne & Warrington, 1962; Erikson, 1966). Integration-masking is believed to disrupt early, pre-representational stages of the target encoding process. It is strongest at an inter-stimulus-interval (ISI) of 0 (i.e., if the two stimuli are presented simultaneously) and under forward masking conditions (i.e., if the mask precedes the target). The second process, inducible by pattern masking, is interruption-masking. *Interruption-masking* means that the mask interrupts the processing of the target before it is completed (i.e., Sperling, 1960). It is obtained under backward-masking conditions (i.e., when the target precedes the mask), occurs at longer ISIs (with maximal masking at an interval of about 30-60 ms) and increases with increasing ISIs (see Bachman & Allik, 1976; Turvey, 1973). The masking function is referred to as U- or J-shaped. Interruption-masking is considered to originate in the primary visual cortex or later (Bachman & Allik, 1976) and to affect later (more central) stages of processing, perhaps including the stage at which the binding of separated features into coherent objects occurs (McClelland, 1978; Turvey, 1973).

The second type of masking involves closely adjacent but non-overlapping contours and is called *metaccontrast-masking* (Averbach & Coriell, 1961; Fehrer & Raab, 1962). It occurs when the shapes of the mask closely fit but do not overlap with the contours of the target. Metaccontrast-masking is most effective at intermediate SOAs (40-80ms). At very short or very long target-mask SOAs the target becomes clearly visible. The cause of this type of masking is thought to include inhibitory interactions between neurons that represent the contours of the target and the mask (Breitmeyer, 1984; Weisstein, Ozog & Szoc, 1975). If the separation between target and masking contours is even slightly increased masking is reliably reduced.

The third type of masking, *object-substitution masking*, was discovered more recently (Di Lollo, Enns, & Rensink, 2000; Enns & Di Lollo, 1997). Here, masking is produced by flanking the target by four dots corresponding to the corners of an imaginary square surrounding the target. Both stimuli (target and mask) are presented simultaneously. If the offset of the dots is delayed relative to the target offset the accuracy in identifying the target drops. Maximum impairment in target discrimination occurs at offset delays of approximately 100-150 ms. Object-substitution masking seems to involve higher-level

attentional and object-recognition mechanisms. Di Lollo et al. (2000) argue that masking by the surrounding dots occurs because a percept, which is based on the four dots, displaces the still developing percept of the target (the dots object induced by the dots substitute the target shape). According to the object-substitution-theory, masking is a consequence of ongoing recurrent communication between neurons at lower and higher levels of processing. Sensory input (e.g., a circle) activates receptive fields of lower level units which then activate units at a higher levels responsible for object-representation (feed-forward-sweep). To bind patterns to spatiotemporal locations and to resolve ambiguity between alternative object activations, a feedback sweep of processing is required to compare the patterns generated at higher levels of processing with ongoing activity at the lower level. If the visual image remains the same during this comparison process the system will become stable in its representation of a given stimulus pattern (e.g., the circle) will become "conscious". If the input activity is changed (i.e., if four dots appear) before the comparison is complete, a mismatch will be detected and the comparison process will begin again based on the new sensory input (the dots), leading to an inability to identify the first stimulus (e.g., the circle).

2.3.2 Effects of visual masking

With the types of masking described above different behavioral effects can be obtained. One dependent variable which can be studied is accuracy of target discrimination. Here, the question of interest is under which conditions observers are unable to identify the target. More frequently, however, visual masking is used to examine the influence of subliminal stimuli (primes) on the processing of subsequent supraliminal stimuli (targets). For instance, Neumann & Klotz (1994) used diamond- and square-shaped objects as imperative stimuli. The task for the participants was to press, for instance, a left key as quickly and accurately as possible whenever the square appears and a right key if a diamond appears. Shortly before target onset, a prime stimulus was presented for a short duration. The prime could either be a smaller version of one of the two target shapes (diamond or square) or a mixture of both stimuli (neutral prime). The size and the shapes of the prime and target stimuli were such that the targets served as metacontrast masks for the primes (see page 18). Three prime-target pairs were used on different trials: response-compatible

pairs, where the prime and the target had the same shape and were therefore mapped to the same response; response-incompatible pairs (prime and target had different shapes and were mapped to different responses); and neutral pairs (a neutral prime not mapped to any response was followed by diamond or square as target). The results showed that participants responded faster to targets if the prime stimulus had the same shape as the target and was thus mapped to the same response (i.e., compatible trials). When primes and targets were mapped to different responses (i.e., incompatible trials), RTs were increased relative to neutral and compatible prime-target pairs (Neumann & Klotz, 1994). Neumann & Klotz (1994) interpreted their results as an effect of direct links between visual information and response parameters without mediation by conscious perception ("direct parameter specification"). The idea is, that in the instruction (and throughout the experiment via practice) an association between response parameters (left, right) and visual information (target shapes, diamond and square) is formed. If now these shapes are presented subliminally in the experiment (i.e., as primes), they automatically trigger the response mapped to them. This response triggering is advantageous on compatible trials because the response which has to be executed has already been partially activated by the prime. On incompatible trials RT costs occur because the prime initially activated the "wrong" response. Similar results have been observed with a number of different paradigms (e.g., Debner & Jacoby, 1994; Kunde, Kiesel, & Hoffmann, 2003; Marcel, 1980; McCormick, 1997; Murphy & Zajonc, 1993). The effect that RTs are shortest with compatible prime-target pairs is called *positive compatibility effect* (PCE). The PCE is usually observed if the time between the onset of the prime and the target is short (<50 ms).

Recently, an effect opposite to the PCE has been observed that may appear counterintuitive at first sight (Eimer & Schlaghecken, 1998; Klapp & Hinkley, 2002; Praamstra & Seiss, 2005). This effect is named *negative compatibility effect* (NCE) and refers to the finding that RTs are shorter with *incompatible* prime - target pairs compared to compatible conditions. A possible sequence of events in an NCE study is as follows: First, a prime (e.g., square or diamond) is very briefly presented (<35 ms). Second, a visual pattern mask (e.g., a composite of the two prime patterns) is presented over the prime location for about 100 ms. Finally, a target (e.g., square or diamond) is presented and participants are asked to report its identity as fast and accurately as possible. Equal to the design by

Neumann & Klotz (1994) response-compatible, response-incompatible, or response-neutral prime-target pairs are possible. Is the duration of the mask short (<30 ms; i.e., at short prime - target SOAs), positive priming effects (PCE) are observed. The NCE usually occurs when the duration of the mask exceeds 50 ms (i.e., with longer prime - target SOAs). Two explanations for this effect can be found in the literature. The first one is that a motor pattern, which has been activated by the masked prime (without conscious awareness, due to e.g., a direct specification of response parameters by its sensory information; Neumann & Klotz, 1994) is *automatically* inhibited later on (*activation-followed-by-inhibition hypothesis*) (Eimer & Schlaghecken, 1998; Klapp & Hinkley, 2002; Klapp & Haas, 2005). Depending on the time interval between prime and target, the inhibition phase may coincide with preparation of the required response and lead to a reversal of positive RT priming effects. Under incompatible conditions (where prime and target are mapped to different responses), this inhibition is advantageous because the initial "incorrect" response activated by the prime is inhibited, allowing a fast activation of the "correct" response and leading to shorter RTs. For compatible trials, however, longer prime-target intervals lead to RT costs because the response activated by the prime is already the "correct" one and its subsequent inhibition leads to a delayed re-activation when the target is processed. The prime-induced motor activation and the subsequent inhibition phase are also distinguishable in movement-related electroencephalographic (EEG) activity (Eimer & Schlaghecken, 1998, 2003; see Figure 2.4). By computing the lateralized readiness potential (LRP; see 2.3.3, page 26 for details), an indicator of response activation, Eimer and Schlaghecken (1998) were able to show that the subliminal primes initially activated their corresponding responses about 200 ms after prime-onset (the A in Figure 2.4). This initial response activation is reversed after approximately 100 ms (the I in Figure 2.4) in an interval in which the target was identified and the appropriate response selected.

Why should an unconsciously activated response be automatically inhibited? Eimer and Schlaghecken (1998) suggest that response activation processes are generally subject to inhibition if a partial response activation is not immediately followed by response execution. One alternative explanation is, that the inhibition occurred because the primes were immediately (SOA = 16 ms) followed by the mask which suddenly removed any sensory information about the prime leading to an interruption of any ongoing response

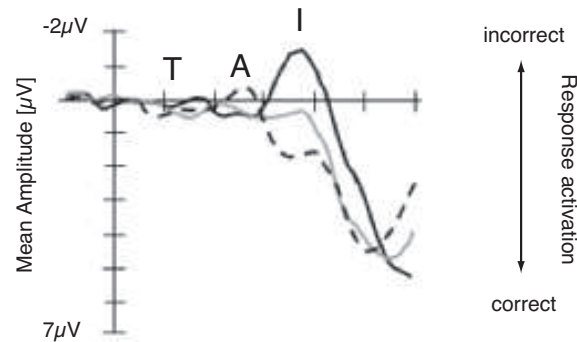


Figure 2.4: The LRP obtained in a subliminal priming task with longer (>50 ms) prime-target SOAs for compatible (black line), neutral (gray), and incompatible (dotted line) trials. The (A) indicates partial prime-consistent response activation (e.g., the primes activated the response assigned to them in the instruction). This activation phase is followed by response inhibition (I). Upward-going (negative) deflections represents incorrect response activation (i.e., activation opposite to the executed response) and downward-going (positive) deflections indicate correct response activation (activation in the direction of the executed response; adapted from Eimer and Schlaghecken, 2003).

activation processes by the visiomotor system (Eimer & Schlaghecken, 1998; Milner & Goodale, 1995).

The second explanation for the NCE is based on the assumption of object-substitution (see 2.3.1, page 18 for details on the object-substitution-hypothesis; Lleras & Enns, 2004). The NCE can arise in this view because of an updating process involving the prime - mask sequence. First, the prime stimulus (e.g., square or diamond) is processed leading to a hypothesis about the prime (e.g., "a square") at higher processing levels. Immediately thereafter this hypothesis is tested by reentrant processing. If a mask has appeared in the meantime, which shares some features with the prime (e.g., a composite of square and diamond), a partial mismatch will be detected and processing will begin again this time based on the presentation of the mask. If the mask remains on the screen for a certain period of time (>50 ms) the comparison of the pattern hypothesized at higher processing levels and the stimulus at lower levels will result in a match. The important point concerning the NCE is that most object updating will include features newly introduced by the mask. If the mask is a composite of the two prime shapes (e.g., square and diamond) new mask-features (e.g., diamond features after a square prime) will determine the priming effect. This would lead to shorter RTs for incompatible prime - target pairs because

the mask activates the percept (and via direct parameter specification presumably the associated response) of the other prime-opposite but target-consistent stimulus. Following this logic, a mask which does not share any features with the prime (e.g., random noise masks) should not induce the opposite percept and response and therefore not lead to a NCE. This is exactly what Lleras and Enns (2004) found. One critical point about their experiments is that the primes remained not entirely unconscious when a random noise mask was used. A mask which is a mixture of the prime shapes has much better masking abilities. Since Eimer and Schlaghecken (2002) found that supraliminal primes do not produce NCE, the results of Lleras and Enns (2004) could also be explained in terms of the different prime visibilities depending on the mask (e.g., random noise masks do not mask efficiently enough, therefore no NCE is observed; composite masks reduce prime visibility much better and therefore lead to NCEs).

The effects reported so far have all been observed in pure forced-choice tasks. There have been few studies investigating the PCE and NCE in free-choice tasks (Klapp & Hinkley, 2002; Schlaghecken & Eimer, 2004; Klapp & Haas, 2005). Since the experiments conducted in this dissertation involve free-choice tasks the question of whether and how subliminal primes influence response selection and execution in such tasks is of importance. Kiesel, Wagener, Kunde, Hoffmann, Fallgatter, & Stöcker (in press) investigated the PCE in a mixed forced- and free-choice metacontrast priming experiment (i.e., forced- and free-choice trials were presented within a block). For both trial types left and right pointing arrows served as primes. On forced-choice trials participants were asked to press a left key in response to a left arrow and the right key in response to a right arrow. The experiment included compatible and incompatible trials. Whenever a double pointing arrow appeared participants were instructed to freely choose one of the two responses. Participants could either choose the primed response (compatible choice) or the unprimed response (incompatible choice). The results showed shorter RTs for compatible- relative to incompatible trials (PCE) for the forced-choice and, importantly, also for free-choice condition. Additionally, a response bias in the sense of reliably more prime-compatible responses choices was found in the free-choice blocks. These findings show that externally presented unconscious stimuli are strong enough to influence free-choice behavior. Accordingly, in NCE paradigms using mixed forced- and free-choice blocks opposite results

as in PCE paradigms should be observed. Indeed, RTs are shorter for incompatible trials as compared to compatible trials on forced-choice trials and more prime-incompatible responses are chosen on free-choice trials (Klapp & Hinkley, 2002; Schlaghecken & Eimer, 2004). Interestingly, on *pure* free-choice blocks (block which contained only free-choice trials) no significant response bias (i.e., equal prime-compatible and -incompatible choices) was observed (Schlaghecken & Eimer, 2004; Klapp & Haas, 2005). The likely function of the intermixed forced-choice trials in mixed blocks seems to be the activation of bonds between specific stimuli and specific responses. This activation must occur during the tested block of trials in order to obtain a NCE on free-choice trials. The authors suggest that the NCE on free-choice trials only occurs if unmasked visible targets enhance the attention to the masked primes on these trials (Klapp & Haas, 2005). Schlaghecken and Eimer (2004) argue that inhibition of an activated response under free-choice conditions is only possible if a task-set (i.e., a certain stimulus-response mapping) is active at the time of task performance which was only the case in mixed forced- and free-choice blocks.

A fundamental question which needs to be addressed when talking about visual masking and subliminal priming is how one can assess whether or not stimuli are perceived with or without awareness. In subliminal priming studies control tasks have to be conducted to investigate whether observers are indeed unaware of the stimuli. Basically, two methods of measuring awareness can be distinguished: Subjective and objective measures (see Merikle & Reingold, 1998; Reingold & Merikle, 1990; Merikle, Smilek, & Eastwood, 2001 for an overview). Subjective measures are based on self-reports. A typical instruction for participants is to indicate whether they saw any stimuli (e.g., "Did you see which figure was presented?"; Sides, 1898; Williams, 1938). With objective measures of awareness observers have to discriminate between alternative stimulus states (forced-choice-discrimination tasks, e.g., "Which stimulus did you see? A diamond or a square?"). Successful discriminations between alternative stimuli indicate awareness, whereas failures to discriminate indicates an absence of awareness (Marcel, 1980, 1883). It has been suggested that in many contexts subjective and objective measures of awareness assess the same underlying conscious experience of perceiving (Merikle et al., 2001).

Most experiments conducted in this thesis use the electroencephalogram (EEG) for electrophysiological measures. More specifically, the lateralized readiness potential (LRP),

a component which can be derived from the EEG is used as an indicator of response activation processes. It is therefore necessary, to discuss the LRP in more detail for a better understanding of the experiments and results of this dissertation.

2.3.3 The lateralized readiness potential (LRP)

The electroencephalogram (EEG) is one of the most important methods to investigate the connection of behavior and brain mechanisms. It is the record of the rhythmical change of electrical activity in the brain, which can be continuously measured at the scalp. Embedded in the spontaneous EEG are neural responses associated with specific sensory, cognitive, and motor events. Using a simple averaging technique it is possible to extract these responses from the spontaneous EEG. These specific responses are called *event-related potentials* (ERPs) because they are associated with specific events. Probably the biggest advantage of using ERPs in cognitive neuroscience is their high temporal resolution which provides a continuous measure of processing between the onset of a stimulus and the response to it. ERPs can be recorded on-line and continuously while cognitive processes are operating and thus can provide temporal information about the functional organization of information processing.

One event related component derived from the EEG is of special interest in this thesis - the *lateralized readiness potential (LRP)*, which is assumed to be related to selective response activation processes (Eimer, 1998). The first to describe movement-related brain potentials in general were Kornhuber and Deecke (1965). They observed an increasing negative shift starting about 1 s before the onset of a hand movement. This so-called *Bereitschaftspotential* (readiness potential, RP) is at first equally large over both hemispheres (i.e., symmetrical). Physiological studies have shown that the RP is generated in the primary motor cortex and in the supplementary motor areas (SMA) of both hemispheres (cf. Arezzo & Vaughan, 1975; Ikeda, Lüders, Burgess, & Shibasaki, 1992; Okada, Williamson, & Kaufman, 1982). About 700 ms before movement onset the RP begins to lateralize (i.e., it becomes asymmetrical). The amplitude over the hemisphere contralateral to the side of a to-be-executed movement becomes more negative than the amplitude over the ipsilateral hemisphere. This lateralization is maximal for recording sites above the motor cortex and becomes smaller for more anterior and superior sites. Therefore, recording sites for the

LRP should lie above central or fronto-central scalp location over the motor cortex (i.e., close to the electrode sites C3 and C4; see Figure 3.7, page 49 for the location of different EEG recording sites). The onset of the lateralization of the RP (i.e., the LRP-onset) reflects the point in time at which the response side (right vs. left hand) is determined (Kutas & Donchin, 1980). The LRP is considered to reflect the activation of response-related processes following stimulus-related processing (i.e., the *relative* activation level of left hand and right hand response tendencies) (Coles, 1989; de Jong, Wierda, Mulder, & Mulder, 1988; Eimer, 1998; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988). It has been applied in the investigation of a number of processes, including the transmission between perception- and response-related processes, motor programming, overlapping task processing, or dual route processing in spatial stimulus response compatibility (e.g., Coles, Gratton, & Donchin, 1988; Miller & Hackley, 1992; Leuthold, Sommer, & Ulrich, 1996; Osman & Moore, 1993; Stürmer, Leuthold, Soetens, Schroter, & Sommer, 2002; Eimer, 1999; Eimer & Schlaghecken, 1998). It has been shown that different parameters of the LRP indicate different cognitive processes (Falkenstein, Hohnsbein, & Hoormann, 1994). For instance, LRP-onset seems to be more closely time-related to central decision processes, whereas the peak of the LRP is thought to be more closely related to the actual response (i.e., to central motor processes).

The LRP can be computed on the basis of stimulus-locked averaged waveforms (i.e., time-locked to the appearance of a stimulus) as well as on the basis of response-locked averages (i.e., time-locked to the response). In stimulus-locked LRPs, latency measures indicate the time between stimulus onset and specific LRP deflections (e.g., LRP-onset). In response-locked LRPs, these latency measures refer to the distance in time between an LRP deflection and the overt response. Response-locked LRP onset latency reflects the duration of processes that take place between LRP-onset and response execution. The onset latency of the stimulus-locked LRP is determined by cognitive processes that occur *prior* to the selective activation of a response. Therefore, pre-motor processes (i.e., influences of stimuli on the decision between response alternatives) are mostly evident in the stimulus-locked LRP (Mordkoff & Gianaros, 2000).

Several methods to calculate the LRP are available (Eimer, 1998). The method used in this dissertation for deriving the (stimulus-locked) LRP is shown in Figure 2.5.

It illustrates the so-called *averaging method* with the formula $[(C4 - C3)_{left\ hand} + (C3 - C4)_{right\ hand}] / 2$ (Coles, 1989; Gratton et al., 1988). Here, the LRP is calculated in two steps. First, the ERP waveforms recorded over motor areas *ipsilateral* to the responding hand are subtracted from ERP waveforms obtained over motor areas *contralateral* to it. These subtractions are performed separately for left hand and right hand responses (see figure caption of Figure 2.5 for details). The resulting two difference waveforms are averaged, and the averaged waveform is the LRP. With this method, an activation of a *correct* response (i.e., activation of the response mapped to or associated with the target) is reflected in the LRP by *negative* deflections, whereas *positive* LRP amplitudes reflect incorrect response activation (i.e., activation of a response which was *not* assigned to a target).

It is important to note, that the LRP is independent of actual overt response execution. It has also been found following pre-cues that predicted the likely side of the upcoming response (Gehring, Gratton, Coles, & Donchin, 1992) as well as on NoGo-trials in so-called Go/NoGo tasks where stimuli can either call for a response (Go-trials) or signal that overt responding has to be suppressed (NoGo-trials)(Miller & Hackley, 1992). Furthermore, the LRP has been found following subliminal primes (Eimer & Schlaghecken, 1998; see 2.3.2 for details). Because stimulus-triggered response activation is also evident if no response has to be executed following the stimulus, the LRP is often referred to as an index of *partial* response activation. It should also be noted that because the LRP is a relative small component a rather large number of single trials is needed to for averaging to obtain reliable waveforms. Eimer (1998) suggested that at least 40-50 trials should be included in the averaged ERP waveforms for both left hand and right hand stimuli.

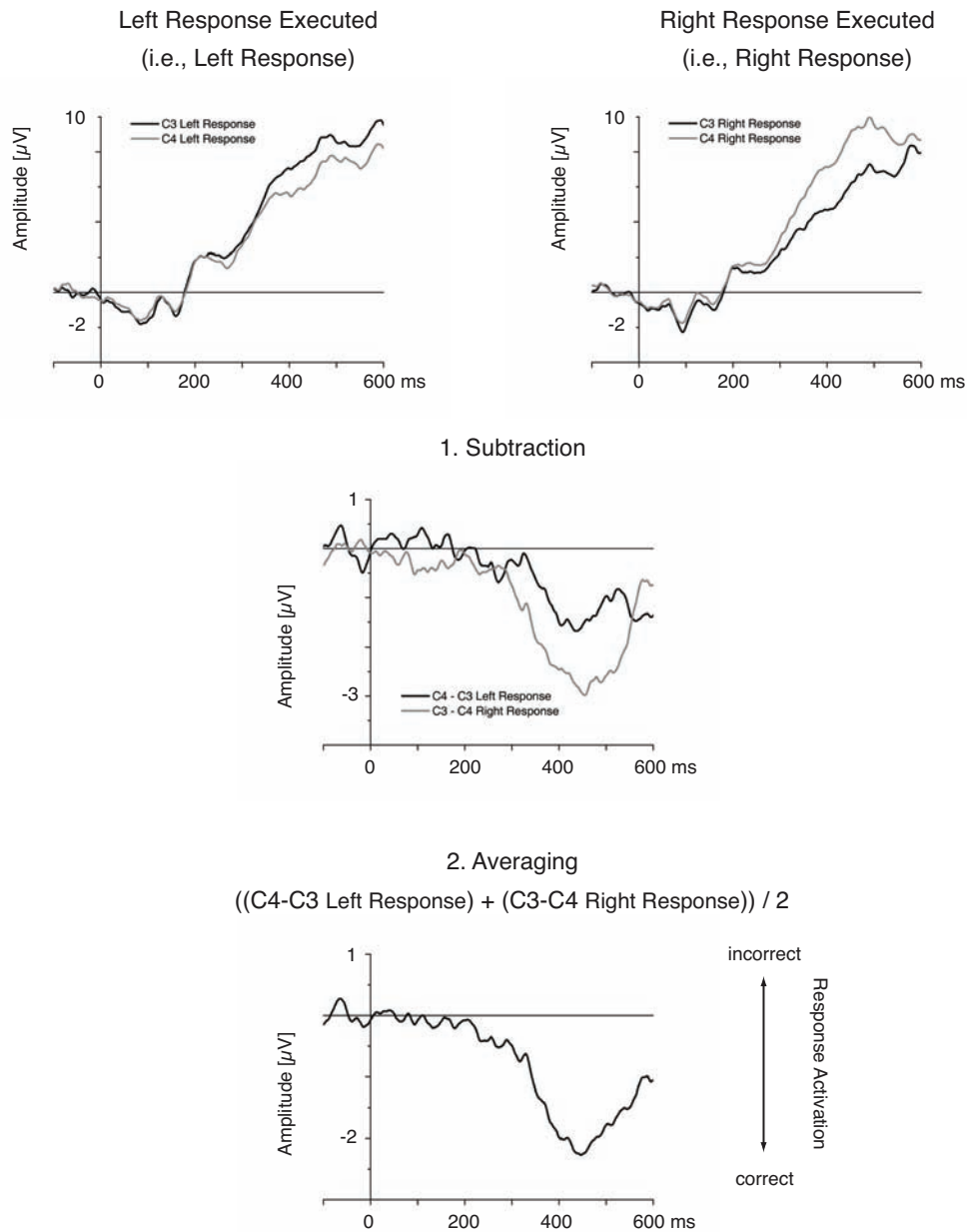


Figure 2.5: **Computation of the lateralized readiness potential (LRP) using the averaging method.** **Top panels:** Possible waveforms elicited at C3 (an electrode positioned over the left motor cortex; black line) and C4 (an electrode positioned over the right motor cortex; gray line) in response to stimuli requiring left hand responses (left panel) and right hand responses (right panel). **Middle panel:** Difference waveforms obtained by subtracting the waveforms elicited at electrodes located ipsilateral to the responding hand from those located contralateral to the responding hand (i.e., C4 - C3 for the left hand responses (black line) and C3 - C4 for the right hand responses (gray line)). **Bottom panel:** The difference waveforms for the two response sides are averaged. For the resulting final LRP waveform negative (downward-going) deflections indicate correct (i.e., target-consistent) response activation and positive (upward-going) deflections indicate incorrect (target-inconsistent) response activation.

2.4 Aim of the thesis

The first objective of this thesis was to provide further evidence for the ideomotor view of action control according to which anticipating action-effect features leads to an *automatic* activation of associated motor codes. The main goal was to show that subliminally presented action-effect stimuli can activate associated response codes although they have not been consciously perceived. To this end, a new approach involving electrophysiological measures (the LRP) in combination with behavioral studies (subliminal priming of actions effects in a free-choice task) was taken.

A secondary aim was to study the role of emotional features of action-effects on action control. Does the emotional valence of an action-effect automatically become integrated into the action representation? To answer this question I examined whether the emotional valence (negative vs. positive) of anticipated action-effects exerts a bias on freely chosen actions.

Chapter 3

Experimental work

The purpose of the experiments reported here was to investigate if subliminally presented action-effect features can *automatically* activate associated motor codes. Specifically, I was interested in the question whether this unconscious response activation elicited by subliminally presented action-effects can influence free-choice actions, a question which has not been fully answered to date. The empirical part consists of five experiments, which aim to yield further insight into the role of action-effects in action control.

To investigate whether subliminally presented action-effects can trigger their associated responses I employed a paradigm similar to one used by Elsner and Hommel (2001; Exp. 2a). Their experiment was divided into two experimental phases - an acquisition-phase and a test-phase. During the acquisition-phase response - effect (R-E) associations were established (between key-press responses and effect-tones), similar to the first stage of the two stage model described in the theoretical background (see 2.1.2, page 4). Immediately after the acquisition-phase the free-choice test-phase was conducted. During the test-phase the authors investigated if the presentation of the former action-effect tones influences free-choice responses. They found, that participants executed significantly more with acquisition-phase consistent key-presses, which indicates that auditory action-effects can automatically activate the response codes associated with them ¹. Elsner and Hommel (2001) concluded that the effect-tones automatically activated the associated response

¹Acquisition-*consistent* means, that the chosen and executed response was the one which has been associated with the prime tone in the acquisition-phase. If the alternative response was chosen (i.e., the one not primed by the tone) the trial type is called acquisition-*inconsistent*; see also Figure 3.1, page 34).

codes thus leading to more acquisition-consistent key-presses. One critical point about the experiments of Elsner and Hommel (2001) is that their effect stimuli were presented above the threshold of awareness. Therefore, participants could in principle use a conscious response strategy, like always pressing a certain key if a certain stimulus appears. If participants were using such deliberate strategies, this would call into question that the response bias obtained in the test-phase was due to automatic response activation by the effect-tones. As noted above, the question if the prime-induced anticipation of action-effect features has to be conscious in order to activate associated motor codes has not been fully answered to date. In the following experiments, subliminal priming paradigms were applied to investigate this question. If the unconscious (i.e., subliminal) presentation of former action-effect features influences free response choices, one can assume that response activation by effect anticipation is indeed an automatic process, since the possibility of conscious response strategies would be reduced or even eliminated.

It has been shown numerous times in forced-choice reaction tasks that subliminal visual stimuli can trigger responses mapped to them by instruction (Neumann & Klotz, 1994; Eimer & Schlaghecken, 2003; see 2.3.2, page 20 for details). Recently, it has also been shown that stimuli, which are presented below the threshold of awareness can trigger assigned responses on free-choice trials in mixed forced- and free-choice blocks (Kiesel et al., in press; Klapp & Hinckley, 2002; Klapp & Haas, 2005; Schlaghecken & Eimer, 2004). First evidence that the presentation of former action-effects which did not reach awareness can activate associated responses stems from a study by Kunde (2004). He showed that if simple key-presses are associated with visual action-effects in a first stage, these action-effects can, if presented subliminally, influence performance in a forced-choice reaction task in a second stage. However, it has not been shown so far that unconscious action-effect features can activate associated responses in a *free-choice task*. Experiment 1 was designed to investigate this issue.

3.1 Experiment 1: Unconscious response priming by action-effects I: Behavioral evidence.

3.1.1 Introduction

Experiment 1 consisted of four parts. In the first part - the *acquisition-phase* - right and left key-presses were followed by contingent visual action-effects (square or diamond shapes) in order to establish response-effect (R-E) associations. In accordance with ideomotor theories of action-control (see 2.1.2, page 4 for details) I assumed that an association between the actions (key-presses) and their immediate sensory effects will be established automatically. To test whether unconscious action-effect features can activate their associated responses, the second experimental part - the *free-choice test-phase* - was conducted. During the free-choice test-phase the same stimuli which had served as action-effects during the acquisition-phase were presented as *subliminal* primes. If an association between the responses and their immediate sensory effects has been formed, the mere presentation of the action-effects should automatically activate the response code associated with this effect, at least to a certain degree (i.e., partial response activation). Since response priming by action-effects is thought to be an automatic process it should also become evident with subliminally presented effect-primes. In particular, response priming by subliminal action-effects should influence the subsequent response choice between responses. If, as assumed, unconsciously presented effect-primes partially activate their associated motor patterns, there should be significantly more acquisition-phase-consistent key-choices (see Figure 3.1 for a description of what is meant by acquisition-phase-consistent and -inconsistent key-choices), similar to the results obtained by Elsner and Hommel (2001; Exp. 2a). If for instance a left key-press was associated with the square stimulus in the acquisition-phase the subliminal presentation of a square as the effect-prime in the test-phase should lead to more left than right free-choice responses (Figure 3.1).

After the free-choice test-phase participants were administered a short questionnaire to examine whether or not they had subjectively noticed or recognized the masked effect-primes or if they could make any comment on the purpose and procedure of the experiment (subjective measure of awareness; see 2.3.2, page 20). The third experimental part was a *forced-choice priming task*, which was conducted to investigate whether the masked prime

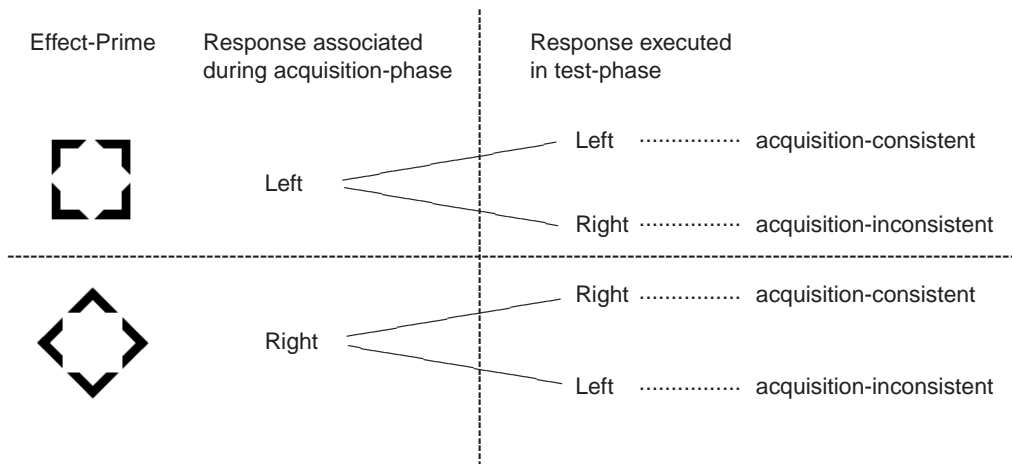


Figure 3.1: **The possible trial-types in the free-choice test-phase.** Depending on the response the prime stimulus was associated with in the acquisition phase there could be acquisition-consistent or acquisition-inconsistent key-choices in the free-choice test-phase (see text for details).

stimuli used in the test-phase can generally influence behavior under conditions usually employed in experiments of unconscious response priming. In the forced-choice priming task the action-effect stimuli from the acquisition-phase were used as imperative stimuli (target) and participants were asked to press a particular key after the appearance of these targets as quickly and accurately as possible (e.g., "Press the right key if the diamond appears and a left key if the square appears."). Shortly before the target stimulus a masked prime was presented (one of the two effect-primes from the test-phase and one additional response-neutral prime). With this design response-compatible, response-incompatible, and neutral prime-target pairs were possible. Participants should respond faster to compatible prime-target pairs as compared to trials where prime and target were completely different stimuli and therefore were mapped to different responses (i.e., incompatible). This result would indicate that the primes activated the response which has been mapped to them in the instruction and that this activation is strong enough to influence the behavioral performance (Neumann & Klotz, 1994; Eimer & Schlaghecken, 2003).

To obtain an objective measure of prime detection (see 2.3.2, page 20 for a comparison of subjective and objective measures of prime awareness) the fourth and final

experimental part - the *prime discrimination task* - was conducted. The task was almost identical to the free-choice test-phase. One of the effect-primers from the acquisition-phase was presented shortly and immediately masked. After the mask a Go-signal appeared and participants were asked to indicate which prime stimulus was presented on each given trial prior to the mask (i.e., to give a prime identification judgement). If the primes are not correctly identified above chance level in this task one can assume that they did not reach awareness even according to a conservative forced-choice criterion (cf. Merikle & Reingold, 1998).

3.1.2 Method

Participants

Twenty-eight volunteers (students from the University of Technology Dresden; age range 18-42 years; 19 female) participated in all four parts of Experiment 1. All participants were naïve to the experimental setting and reported normal or corrected to normal vision. None of the participants had a history of neurological or psychiatric disorders. They were either paid 5 Euro per hour or received course credit for their participation.

Stimuli, procedure, and design

For all experiments a PC computer attached to a VGA color monitor with a refresh rate of 75 Hz was used for stimulus presentation. All experiments were performed using Presentation[®] software (Version 0.80, www.neurobs.com). For all experiments the response keys were the 'Y' key (left response) and the '-' key (right response) on a standard German computer keyboard. Participants were instructed to use their left and right index finger for response execution. All experiments were analyzed using SPSS 11.5 for statistical analysis and Vison Analyzer (BrainProducts, Munich) for EEG data analysis.

Acquisition-phase

The stimuli and timing of the acquisition-phase are shown in Figure 3.2. The action-effect stimuli consisted of two black shapes, a square and a diamond, which were presented on

a white background at the center of the monitor screen. The two shapes extended 1.8 cm in width and heights (at a viewing distance of 60 cm this corresponds to $\sim 1.72^\circ$ of visual angle). The fixation cross was black and extended 1 cm in width and heights.

Each trial of the acquisition-phase started with the presentation of the fixation cross accompanied by a tone (800 Hz) which served as a Go-signal. Participants were instructed to press one of the two possible keys on the computer keyboard (left or right) with their index finger in response to the Go-signal. They were told that it did not matter for the task which of the two keys they pressed on each given trial. They were instructed to press both keys approximately equally often. 50 ms after the key press an action-effect stimulus, which was contingent on the executed response appeared at the center of the screen. For half of the participants a left key-press was followed by the diamond and a right key-press by the square (and vice versa for the other half). The action-effect stayed on the screen for 500 ms and was followed by a blank screen, which was displayed for 1200 ms. Then a new trial started. The participants were not informed about the purpose of the task. If they asked about the purpose of the effect stimuli they were told that they are needed for experimental control purposes but were not relevant for the task itself. They were not explicitly asked to ignore the action-effects. The dependent variable was key-choice (left, right [%]). The acquisition-phase consisted of 200 trials divided into 4 experimental blocks with 50 trials each. After each block a short break was allowed. At the beginning a practice block of 10 trials was given to familiarize the participants with the task.

Free-choice test-phase

Immediately after the acquisition-phase the free-choice test-phase was conducted. The stimuli and timing are presented in Figure 3.3. The square and diamond shapes used as action-effects in the acquisition-phase served as effect-primers in the test-phase. Both primers extended 1.2 cm in width and heights ($\sim 1.14^\circ$ visual angle). The mask was a composite of the two prime shapes and extended $\sim 1.72^\circ$ of visual angle. The Go-signal consisted of the same cross and tone used in the acquisition-phase.

Each trial of the test-phase started with the presentation of an effect-prime (square or diamond) at the center of the screen for 32 ms. After the offset of the prime a blank screen appeared for 32 ms and then the mask was displayed for 32 ms. Immediately after

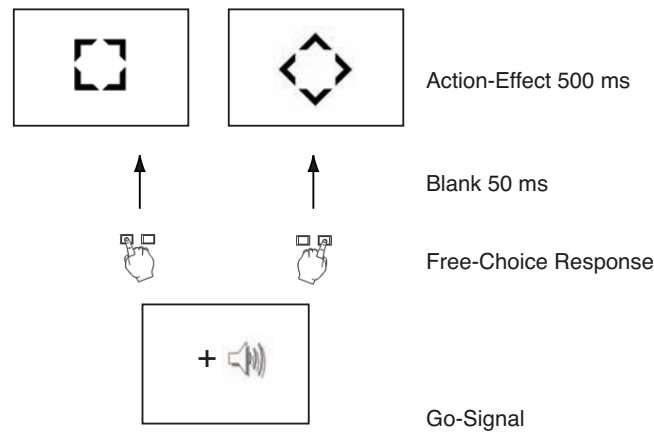


Figure 3.2: **The sequence of events during a trial of the acquisition-phase of Experiment 1.** In reaction to a Go-signal participants had to freely choose to press one of two possible response keys. 50 ms after the key-press and contingent on it, a visual action-effect appeared.

the offset of the mask the cross and the tone were presented simultaneously serving as a Go-signal. Participants were instructed to freely choose to press one of the two keys already known from the acquisition-phase in response to the Go-signal. They were asked not to think about which of the two possible keys they wanted to press in advance but instead to react as spontaneously and fast as possible. The test-phase consisted of 10 practice trials and 100 experimental trials divided into two blocks. The two effect-primers were presented in a randomized order with the constraint that each primer appeared 50 times. The dependent variable was key-choice [%]. There could be either acquisition-consistent or acquisition-inconsistent key-choices depending on the primer presented prior to the key-press (see Figure 3.1, page 34).

Questionnaire

After the free-choice test-phase participants filled out a short questionnaire to investigate whether they were subjectively able to identify the prime-stimuli (see appendix C).

Forced-choice priming task

The stimuli and timing of the forced-choice priming task are presented in Figure 3.4. The primes and the mask were identical to those used in the free-choice test-phase. Additionally, a neutral prime (a star shaped overlay of the two other primes, identical to a smaller

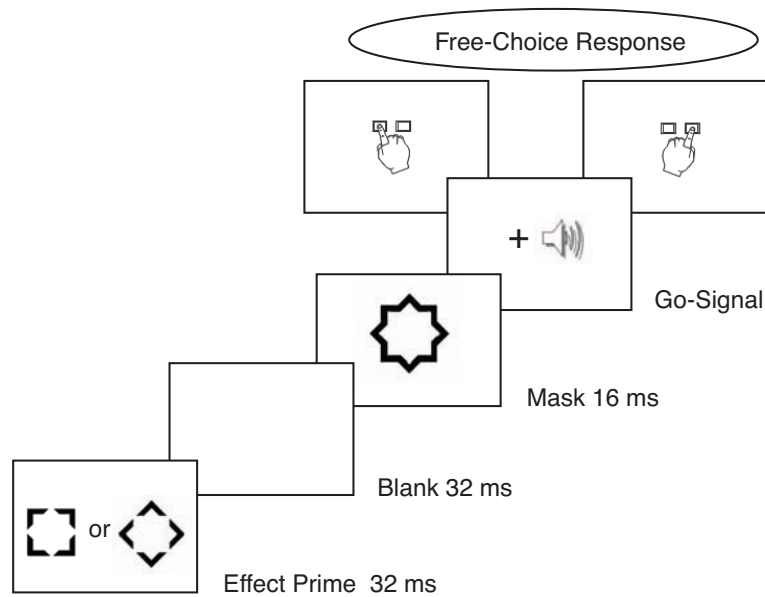


Figure 3.3: The sequence of events in a trial of the free-choice test-phase of Experiment 1. After a Go-signal participants were asked to freely choose to press one of two possible response keys. Unknown to them, one of the action-effect stimuli from the acquisition-phase was presented and masked before each Go-signal.

version of the mask) extending $\sim 1.14^\circ$ of visual angle was introduced. The target stimuli were the square and diamond shapes used as action-effects in the acquisition-phase.

Each trial started with the randomized presentation of one of the three prime stimuli for 32 ms. After the offset of the prime a blank screen appeared for 32 ms followed by the mask (for 16 ms). Right after the offset of the mask one of the two target stimuli (square or diamond) appeared at the center of the screen for 100 ms. The participants who had received a square as action-effect after pressing the left key in the acquisition-phase were instructed to press the left key as fast and as accurately as possible whenever the target was a square (and the right key if the target was a diamond). The remaining participants received the opposite target-response mapping which was also in accordance with the mapping they had received in the acquisition-phase. This was done to avoid interference from different S-R associations acquired in the acquisition-phase. After response execution an inter-trial-interval of 1200 ms started. The independent variable was (response-) compatibility (compatible, neutral, incompatible). On *compatible* trials the

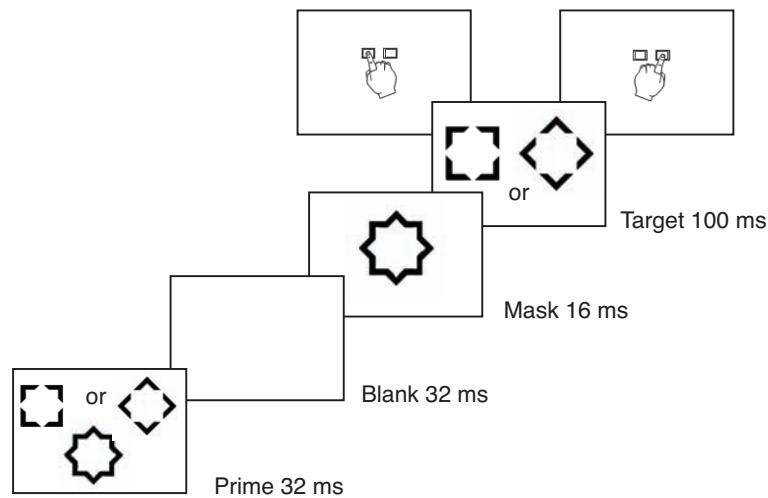


Figure 3.4: **The sequence of events in a trial of the forced-choice priming task of Experiment 1.** First, a prime was shortly presented and masked. Then a target appeared and participants had to respond to it as quickly as possible according to a rule assigned to them in the instruction.

prime and the target had the same shape and were therefore mapped to the same response; on *incompatible* trials prime and the target had different shapes and were thus mapped to different responses, and on *neutral* trials the prime was not mapped to any response. The task consisted of 192 trials divided into 3 experimental blocks of 64 trials each (there were 20 additional practice trials at the beginning). After each block a short break was allowed. Each response compatibility condition was instantiated by 64 trials. The dependent variables were RT [ms] and error rate [%].

Prime discrimination task

In the prime discrimination task exactly the same stimuli and timing were used as in the free-choice test-phase (Figure 3.5), but subjects had to perform a different task. In the instruction subjects were informed that before each mask one of two prime stimuli would appear very briefly and that these primes would be very hard to identify. After the appearance of the Go-signal participants were asked to indicate which prime stimulus they had perceived prior to the mask - a square or a diamond. Participants were allowed to guess when they felt unable to identify the prime. Half of the subjects were instructed to press the left key if they identified a square and the right key if it was a diamond (and vice versa

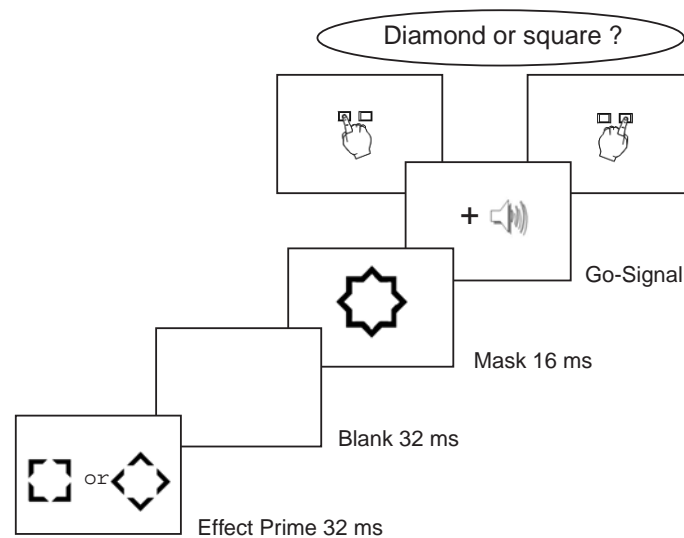


Figure 3.5: **The sequence of events in a trial of the prime discrimination task of Experiment 1.** First, one of the effect-primers was shortly presented and masked. After a Go-signal, participants had to indicate which prime stimulus was presented before the mask.

for the other half; for each participant the response mapping was in accordance with the mapping of the acquisition-phase and forced-choice priming task). The task was divided into 2 experimental blocks (50 randomized trials per block; each effect-prime appeared 50 times). At the beginning 10 practice trials were administered. The dependent variable was the proportion of correctly identified primes [%].

3.1.3 Results

Acquisition-phase

The mean key-choice frequency was computed (i.e., how many times each of the two possible response keys was chosen). There was no reliable difference between the frequencies with which the two keys had been chosen (51.6% [Standard error of mean (SE mean) 1.0] vs. 48.4% [SE mean 1.0] , $(t(27) = 1.61, p > .10)$). Thus the two effect stimuli were produced approximately equally often.

Free-choice test-phase

Three subjects had to be excluded because of pressing only one key in reaction to the Go-signal throughout the task ². This left 25 subjects for further analysis. Participants did not execute any response within a time window of 4 s on 5.7% of the trials (these trials were excluded before further analyses). On average, participants chose the acquisition-consistent key on 52.8% [SE mean 1.24] and the acquisition-inconsistent key on 47.2% [SE mean 1.24] of all trials. A two-tailed paired t-test revealed this difference to be significant ($t(24) = 2.28, p < .05$).

An analysis of the RTs revealed no significant difference between acquisition-consistent and -inconsistent trials (212 ms [SE mean 11.4] vs. 209 ms [SE mean 11.1] for consistent and inconsistent trials, respectively; $t(24) = .893, p > .50$). A further analysis in which all subjects who responded with an obvious strategy were excluded was conducted. Ten more subjects pressed the two response keys more or less alternating. The exclusion of these subjects did not change the basic results. There were significantly more acquisition-consistent than -inconsistent key choices (53.43% [SE mean 1.5] vs. 46.57% [SE mean 1.5], $t(14) = 2.28, p < .04$) and no difference in the RTs (222 ms [SE mean 12.7] vs. 221 ms [SE mean 11.8] for consistent and inconsistent trials, respectively; $t(14) = .172, p > .80$).

Questionnaire

None of the subjects correctly identified the purpose of the task nor did any subject correctly report the shape of the primes. Most participants did not notice the existence of the primes at all.

Forced-choice priming task

Mean RTs of correct responses for each condition are presented in Figure 3.6. RT outliers (RTs faster than 100 ms and slower than 2000 ms and RTs which deviated above or below an absolute value of $z = +/- 2.0$ compared to the mean; 1.8% of all trials) and trials on which a response error was made (2.1% of all trials) were excluded before further anal-

²Including these participants did not change the results (52.52% [SE mean 1.16] acquisition-consistent key-choices, 47.49% [SE mean 1.16] acquisition-inconsistent key-choices; $t(27) = 2.16, p < .05$. The same was true for the RTs (208 ms [SE mean 10.4] vs. 206 ms [SE mean 10.1] for consistent and inconsistent key-choices, respectively; $p > .60$)

ysis. The RTs were analyzed by means of a within-subjects repeated measures analysis of variance (ANOVA) with the the factor compatibility (compatible, neutral, incompatible). The analysis revealed a significant main effect ($F(2,48) = 15.03$, $MSe = 260.64$, $p < .001$). Planned comparisons showed that this effect was due to significantly faster RTs on compatible trials (485 ms [SE mean 9.9]) as compared to neutral (502 ms [SE mean 10.3], $t(24) = 3.59$, $p < .001$) and incompatible trials (509 ms [SE mean 9.8], $t(24) = 4.88$, $p < .001$). The comparison between neutral and incompatible trials did not reach significance ($t(24) = 1.84$, $p > .07$).

The mean error rates were 1.7% [SE mean .31], 1.9% [SE mean .38] and 2.1% [SE mean .25] for compatible, neutral and incompatible trials, respectively. An ANOVA with the factor compatibility (compatible, neutral, incompatible) revealed no significant main effect ($F(2,48) = .08$, $MSe = 1.19$, $p < .50$).

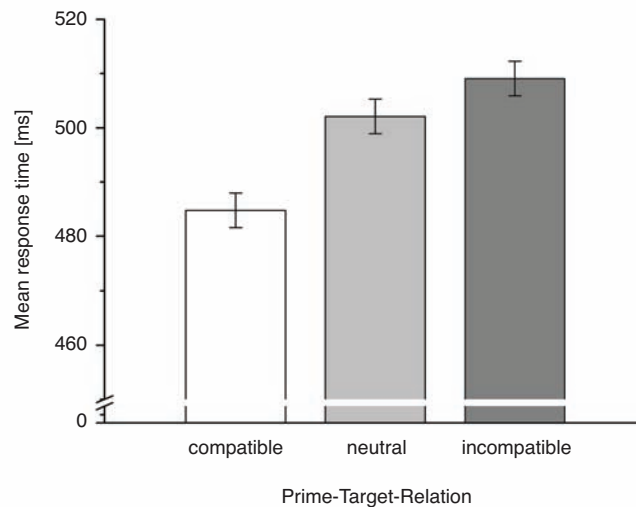


Figure 3.6: Mean correct response times (RTs) for compatible (white), neutral (light gray), and incompatible (dark gray) trials of the forced-choice priming task of Experiment 1. Error bars show 95% within-subjects confidence intervals (Loftus & Masson, 1994).

Prime discrimination task

The proportion of correct and incorrect key-presses was calculated for each participant. On average the primes were correctly identified on 49.9% [SE mean 1.1] of the trials, which was not significantly different from chance level ($t(24) = .018$, $p > .50$).

3.1.4 Discussion

Experiment 1 aimed to show that subliminally presented action-effects can bias response choice in a free-choice reaction task. During the acquisition-phase two simple key-press responses produced visual effects. Both effects were produced equally often, thus it can be assumed that both R-E associations have been established equally strong. The action-effects were used as masked primes in the subsequent free-choice test-phase to investigate whether the subliminal presentation of former action-effects, which are not consciously perceived, can nevertheless influence free-choice actions. The results of the test-phase indicate that this was the case. Reliably more acquisition-phase consistent responses were chosen. In accordance with other authors these results indicate that the actions (key-press responses) and their immediate sensory effects (visual shapes) were integrated automatically (Elsner & Hommel, 2001). The most likely interpretation of the response bias observed in the free-choice test-phase is that the effect-primes automatically activated their corresponding (associated) motor codes and that this activation was in most cases sufficient enough to influence subsequent behavior (i.e., response execution). That the ratio of acquisition-consistent and -inconsistent key-choices is rather small is not surprising. As noted in the theoretical background (2.1.2, page 4), response priming by effect features does not necessarily lead to an automatic execution of the activated response because response activation and response execution are independent stages of the action planning process (Elsner & Hommel, in press).

The failure of the participants to subjectively (verbal report) and objectively (forced-choice discrimination) indicate which effect-prime was presented indicates that the primes did indeed not reach awareness (see 2.3.2 for a details on subjective and objective measures of awareness). Nevertheless, the same primes systematically influenced performance in a forced-choice reaction task either by activating the response which was assigned to them in the instruction (priming at the motor level), or alternatively facilitation encoding and identification of the target stimulus (i.e., perceptual priming) (cf. Neumann & Klotz, 1994).

Although the results of the test-phase of Experiment 1 show that unconscious action-effects can influence free-choice responses, the data cannot directly answer the question if it was prime-induced response activation, which led to this bias. In order to clarify this

question it is necessary to apply a method that allows one to continuously track the time course of response activation processes after the presentation of the prime. Therefore, Experiment 2 was conducted using the electroencephalogram (EEG) and specifically the lateralized readiness potential (LRP) as an indicator of response activation.

3.2 Experiment 2: Unconscious response priming by action-effects II: A LRP study.

3.2.1 Introduction

To investigate if the response bias observed in the free-choice test-phase of Experiment 1 was indeed due to automatic response activation by unconscious action-effect primes it is necessary to use a method which allows one to investigate response activation more directly. For this reason Experiment 2 was conducted. It consisted of the same four sub-tasks (acquisition-phase, free-choice test-phase, forced-choice priming task, prime discrimination task). During the free-choice test-phase and the forced-choice priming task the EEG was recorded to investigate the time course of the cognitive and motor processes involved in these tasks. Specifically, we were interested in an event-related potential which can be isolated from the spontaneous EEG - the LRP, which has been proven to be a reliable indicator of response activation processes (see 2.3.3, page 26 for details). With the LRP as an indicator of response activation we are able to investigate whether or not the effect-primes do indeed activate associated motor codes.

For methodological reasons the design of the test-phase was changed. In a pilot EEG-study where only Go-trials were included in the test-phase (which was thus identical to the free-choice test-phase of Experiment 1) some major problems occurred. Because of the fast response times to the Go-signal it did not become clear from the LRP which part of the waveform was due to response activation by the primes (prime-related activity) and which part was caused by the activation of the subsequently executed response (response-related activity). The stimulus-locked LRP usually starts within a time-window of 150 - 250 ms after stimulus onset, a time window during which a number of the free-choice responses in the pure Go-trial test-phase have already been executed. This becomes evident by looking at the RTs of the test-phase of Experiment 1 (mean RT 210 ms). In the pilot

EEG-study the responses were equally fast (mean RT 206 ms). Fortunately, the response bias (i.e., more acquisition-consistent than inconsistent key-choices) could be replicated. Nevertheless, the aim of the EEG experiment was to reveal prime-induced response activation. Therefore a new paradigm which allowed it to isolate prime-related motor activation was needed. One possibility is a Go/NoGo paradigm. A study conducted by Schlaghecken and Eimer (2001) showed that priming effects are not affected by response frequency. They varied the amount of trials on which a response had to be withheld (NoGo-trials) in comparison to trials where a certain response had to be executed (Go-trials). The results (equally strong priming effects in all conditions) showed that the strength of the priming effect does not depend on the ratio of Go/NoGo-trials. This indicates that neither the general ability of masked primes to elicit a partial motor activation nor the specific time course of this process is influenced by the presence or absence of NoGo-trials. Most important for the present purpose, adding NoGo-trials to the free-choice test-phase makes it more likely that the participants wait until the appearance of the Go-signal before executing the response (i.e., there will be less anticipatory responses). The postponing of the activation of the finally executed response should allow one to get a clearer picture of motor-related activity induced by the primes. Additionally, the Go/NoGo design could help the participants to stay focussed on the task. Because more trials are needed in each conditions, to calculate the LRP, the task could become very tiring. Importantly, it would also make it less possible that participants decide in advance of the visual display which response they are going to make if the next Go-signal appears³. This advance decision appears more likely in a pure free-choice task because the predetermined response would always be appropriate. Another interesting aspect that this design allows to investigate is possible response activation by the primes on the NoGo-trials. It has been shown with forced-choice reaction paradigms that reliable response activation also takes place on trials where responses have to be withheld (Hackley & Miller, 1992).

The following predictions can be made for the LRP data of the free-choice test-phase of Experiment 2: First, prime-related response activation should be visible in the LRP waveforms starting about 200 ms after prime-onset for the Go- and NoGo-trials. On Go-

³Of course, participants could in principle still apply a response strategy like saying "When the next Go-signal appears I will press the right key".

trials, the acquisition-consistent and -inconsistent LRP waveforms should exhibit different shapes. On acquisition-consistent trials (on which participants executed the response associated with the effect-prime) a prime-induced activation of the consistent response should be visible starting at about 200 ms after prime-onset. Activation of the consistent response should then continue to increase until response execution. In contrast, on acquisition-inconsistent trials (on which participants finally executed the alternative response which was *not* associated with the effect-prime) the same initial, prime-induced activation of the acquisition-consistent response should be visible, which should, however, reverse after some time leading to an activation of the finally executed acquisition-inconsistent response. In other words, on acquisition-inconsistent trials an initial activation of the response opposite to the one executed should be visible. As a control condition the EEG was also recorded during the forced-choice priming task. Here, the waveform on response-compatible trials should exhibit a similar shape as the acquisition-consistent waveform on the Go-trials of the free-choice test-phase. On incompatible trials, an early activation of the incorrect (alternative) response should be present and then reverse into activation of the correct response. On neutral trials no prime-related response activation should be visible.

3.2.2 Method

Participants

Twenty-five new, naïve volunteers (age between 19 and 33 [mean age 22.8], 13 females, all right-handed) participated in Experiment 2. All participants had normal or corrected to normal vision and reported no history of neurological or psychiatric disorders. They received either 5 Euro or course credit for their participation.

Stimuli, procedure, and design

The participants were seated in a sound-proof, electrically shielded chamber. The experiment started with the acquisition-phase, followed by the free-choice Go/NoGo-test-phase, a questionnaire for subjective awareness, the forced-choice priming task, and the prime discrimination task. It took about 2.5 hours to complete the experiment.

Acquisition-phase

The stimuli, timing, and design of the acquisition-phase were identical to that of Experiment 1 (Figure 3.2, page 37).

Free-choice test-phase

The stimuli of the test-phase were identical to the ones used in Experiment 1 (Figure 3.3, page 38). Each trial started with the presentation of an effect-prime for 32 ms which was followed by a blank screen (32 ms) and a mask (16 ms). In 50% of all trials a cross appeared after the offset of the mask. This was the Go-signal indicating to the participants to freely choose to press one of the two keys already known from the acquisition-phase. On the remaining trials a different symbol (#) appeared after the mask. Participants were instructed not to respond at all whenever this symbol appeared (NoGo-trials). In the case of a Go-trial the effect stimulus already known from the acquisition-phase (with the same R-E mapping) appeared after the key-press. This was done to maintain the strength of the R-E association throughout the test-phase because the larger number of trials could have led to a weakening of the R-E-binding. The test-phase consisted of 20 practice trials and six experimental blocks of 56 trials each (336 trials overall; 168 Go-trials, 168 NoGo-trials). The independent variables were effect-prime (square, diamond) and trial type (Go, NoGo). The dependent variables were the type of key-choice (acquisition-phase consistent, acquisition-phase inconsistent) [%] and LRP waveforms [μV].

Questionnaire

After the free-choice test-phase participants filled out a short questionnaire to investigate whether they were subjectively able to identify the prime-stimuli (see appendix C).

Forced-choice priming task

The stimuli and timing of the forced-choice priming task were identical to that of Experiment 1 (Figure 3.4, page 39). It consisted of 12 blocks with 40 trials each (480 trials overall; 160 compatible, neutral, and incompatible trials). The independent variable was response-compatibility (compatible, neutral, incompatible). The dependent variables were RT [ms], error rate [%], and LRP waveforms [μV].

Prime discrimination task

The stimuli and timing of the prime discrimination task were identical to those of Experiment 1 (Figure 3.5, page 40). It consisted of 4 experimental blocks of 50 trials each (200 trials overall). Each effect-prime was presented randomly 100 times. The dependent variable was key-choice (hit, error) [%].

EEG data acquisition

The EEG was recorded using Ag-AgCl electrodes from 6 positions over the pre-motor cortex (C3, C4 [according to the 10:20 system (Jaspers, 1958)], C1 [2cm to the right of C3], C2 [2 cm to the left of C4], FC3 [2 cm in front of C3], FC4 [2cm in front of C4]) and three additional electrodes (Cz, PO7, PO8). Figure 3.7 shows the position of the electrodes on the scalp. The vertical electrooculogram (EOG) was recorded from an electrode placed under the left eye and the horizontal EOG from two electrodes 1 cm external to the outer canthus of each eye. All recording sites and the right-mastoid were recorded with a left-mastoid reference electrode and then re-referenced offline to the average of the left and right mastoid (Nunez, 1981). The EEG and EOG were digitized at a rate of 1000 Hz with a high-pass filter of 0.016 Hz (time constant = 10 s) and a low-pass filter of 80 Hz by a PC. All impedances were kept below 5 k Ω throughout the experiment. The EEG was stored and filtered offline with a low-pass filter of 30 Hz.

EEG data analysis

For the calculation of stimulus-locked (i.e., prime-locked, time 0 = the onset of the prime) components the EEG-signal was segmented into segments of 700 ms length reaching from -100 ms pre-stimulus (before prime-onset) to 600 ms post-stimulus (after prime-onset). The period 100 ms before prime-onset until prime-onset was used as a baseline (the mean amplitude within this time window was set to zero). After segmentation, artifacts were rejected after visual inspection or if the maximum voltage in the segment extended +/- 50 μ V. After artifact rejection all segment belonging to one condition were averaged.

The LRP was calculated stimulus-locked using the averaging method with the formula $[(C4 - C3)_{left\ hand} + (C3 - C4)_{right\ hand}] / 2$ (Gratton et al., 1988; Coles, 1989; see 2.3.3, page 26 for details). It is important to explain the different ways the stimulus-locked

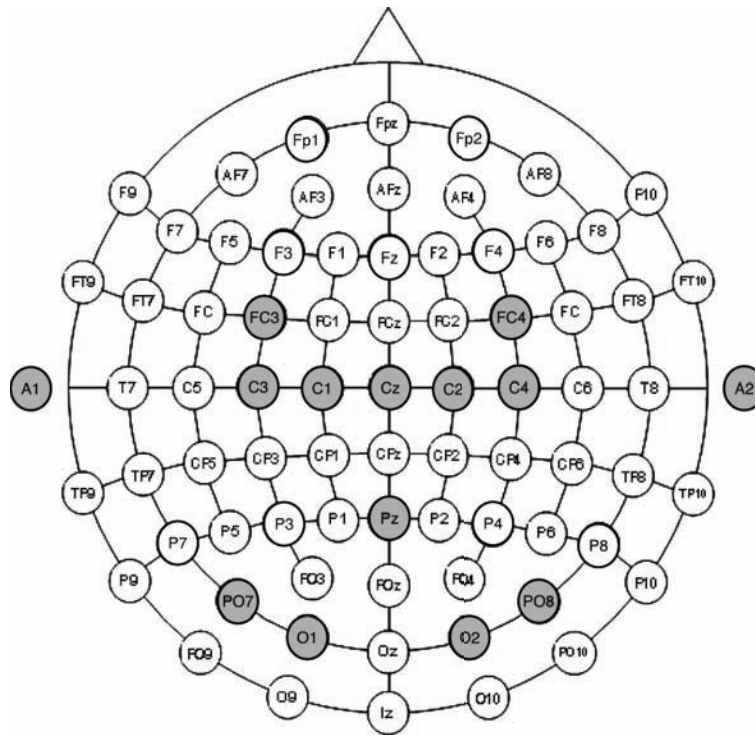


Figure 3.7: **The electrode sites used for EEG data acquisition.** The sites used in Experiment 2 are shown in gray.

LRP was calculated for the (1) free-choice test-phase and the (2) forced-choice priming task.

(1) *LRP calculation for the free-choice test-phase:* For the free-choice test-phase the LRP was first calculated separately for the Go- and NoGo-trials. Here, the LRP was derived contingent on the prime which was presented (*prime-related LRP*). For the prime-related calculation, the LRP was calculated relative to the response side with which the prime was associated in the acquisition-phase. In this case left in the LRP formula means that the prime was associated with the left response in the acquisition-phase and right means that the prime was associated with the right response; $[(C4 - C3)_{left\ prime} + (C3 - C4)_{right\ prime}] / 2$. Thus a negative-going LRP deflection indicates activation of the response that was associated with the effect-prime in the acquisition-phase (acquisition-consistent response activation), whereas a positive-going LRP deflection indicates activation of the alternative response (acquisition-inconsistent response activation). It is im-

portant to note that in this analysis, the LRP is computed independently from which response the participant actually performed. Given that participants chose left and right responses approximately equally often, the lateralization of the readiness potential for left and right responses will cancel out in this computation. Any lateralization that will be seen in the resulting waveforms can thus unequivocally attributed to response activation elicited by the primes. In particular, I expect that the primes will elicit an early (around 150-250 ms post-prime) activation of the motor response it was associated with in the acquisition-phase.

In a follow-up analysis the Go-trials were split into whether an acquisition-consistent or -inconsistent response had been executed. For these two trial types (acquisition-consistent and acquisition-inconsistent) separate LRP waveforms were calculated but this time relative to the chosen response (*response-related LRP*; see Figure 3.9). Here, left in the LRP formula means that the left response was executed and right means that the right response was executed; $[(C4 - C3)_{\text{left response}} + (C3 - C4)_{\text{right response}}] / 2$. In the resulting LRP waveforms for acquisition-consistent responses, prime-induced response activation should be evident in an LRP deflection in the same direction as the final response, whereas for acquisition-inconsistent responses, prime-induced response activation should show up in an LRP deflection in the *opposite* direction as the finally executed response. For example, if the effect-prime was associated with the left response, but participant chose to execute the right response, prime-induced response activation should be evident in an early LRP deflection indicating activation of the left response, which later should reverse into activation of the actually executed (inconsistent) right response.

(2) *LRP calculation for the forced-choice priming task*: For the forced-choice priming task the LRP was first calculated response-related, separately for response-compatible, neutral, and incompatible trials (see Figure 2.5, page 29; On the figure an example for a compatible trials is given. On incompatible trials an initial activation of the incorrect response should be visible around 200 ms. On neutral trials no prime-induced response activation should be evident). Secondly, the LRP was calculated prime-related (depending on the hand the prime-stimulus was mapped to in the instruction) including the pooled compatible and incompatible trials to evaluate overall prime-related response activation (since the neutral

prime was not mapped to any response, the neutral trials were not included in this calculation). This measure is comparable to the prime-related LRP waveform from the Go- and NoGo-trials of the free-choice test-phase.

For both tasks (test-phase and forced-choice priming task) the LRP formula was applied to the electrode pairs C3/C4, FC3/FC4. The activity obtained from these two electrode pairs was pooled (averaged) and will be referred to as the LRP from now on.

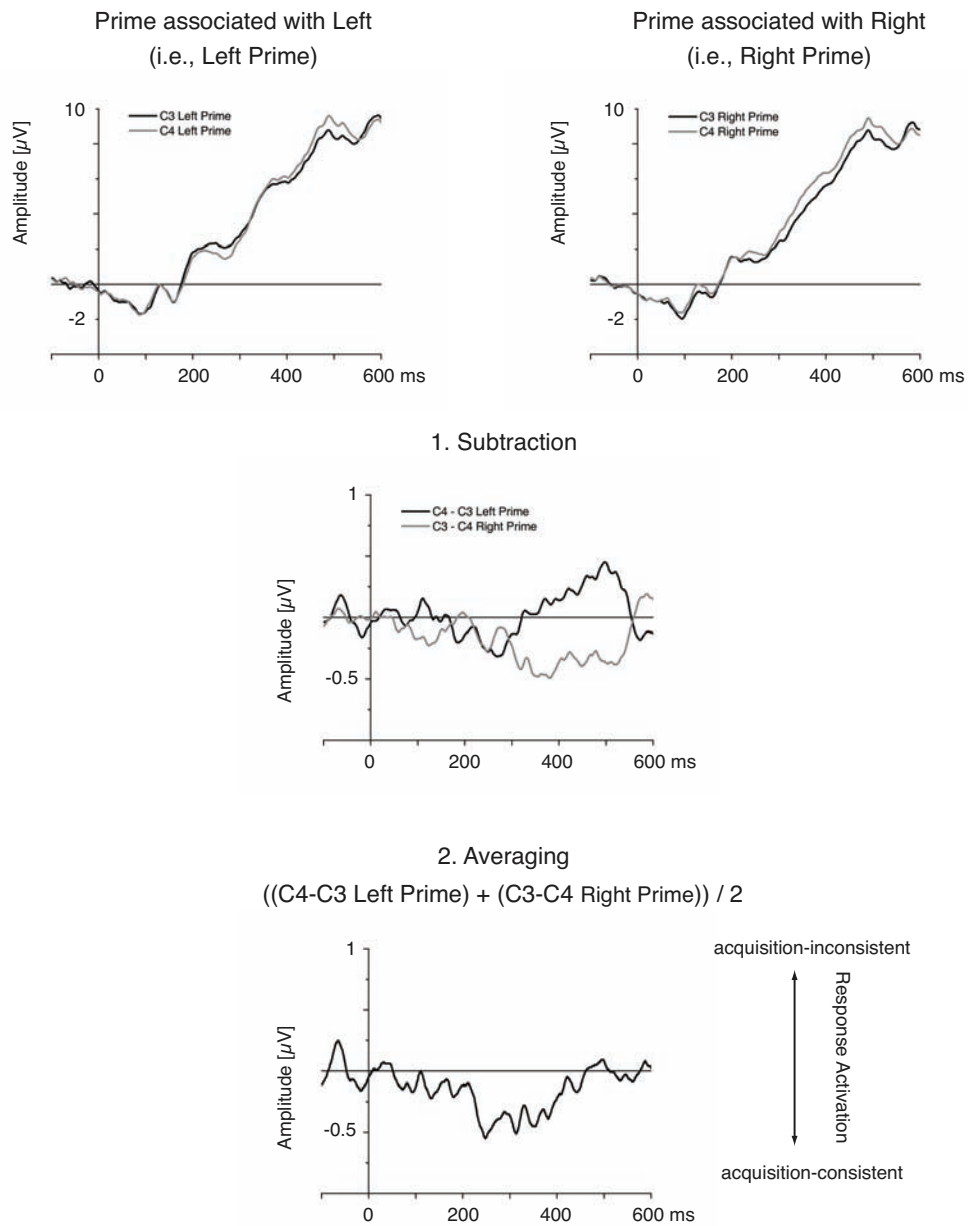


Figure 3.8: **Prime-related computation of the LRP using the averaging method.** **Top panels:** Possible waveforms elicited at C3 (an electrode positioned over the left motor cortex; black line) and C4 (an electrode positioned over the right motor cortex; gray line) after the presentation of primes associated with left responses (left panel) and right responses (right panel). **Middle panel:** Difference waveforms obtained by subtracting the waveform of C3 from C4 for the prime associated with left (black line) and from subtracting the waveform of C4 from C3 for the prime associated with right (gray line). **Bottom panel:** The difference waveforms are averaged. For the final prime-related LRP waveform negative (downward-going) deflections indicate prime-consistent (i.e., acquisition-consistent) response activation and positive (upward-going) deflections indicate prime-inconsistent (i.e., acquisition-inconsistent) response activation.

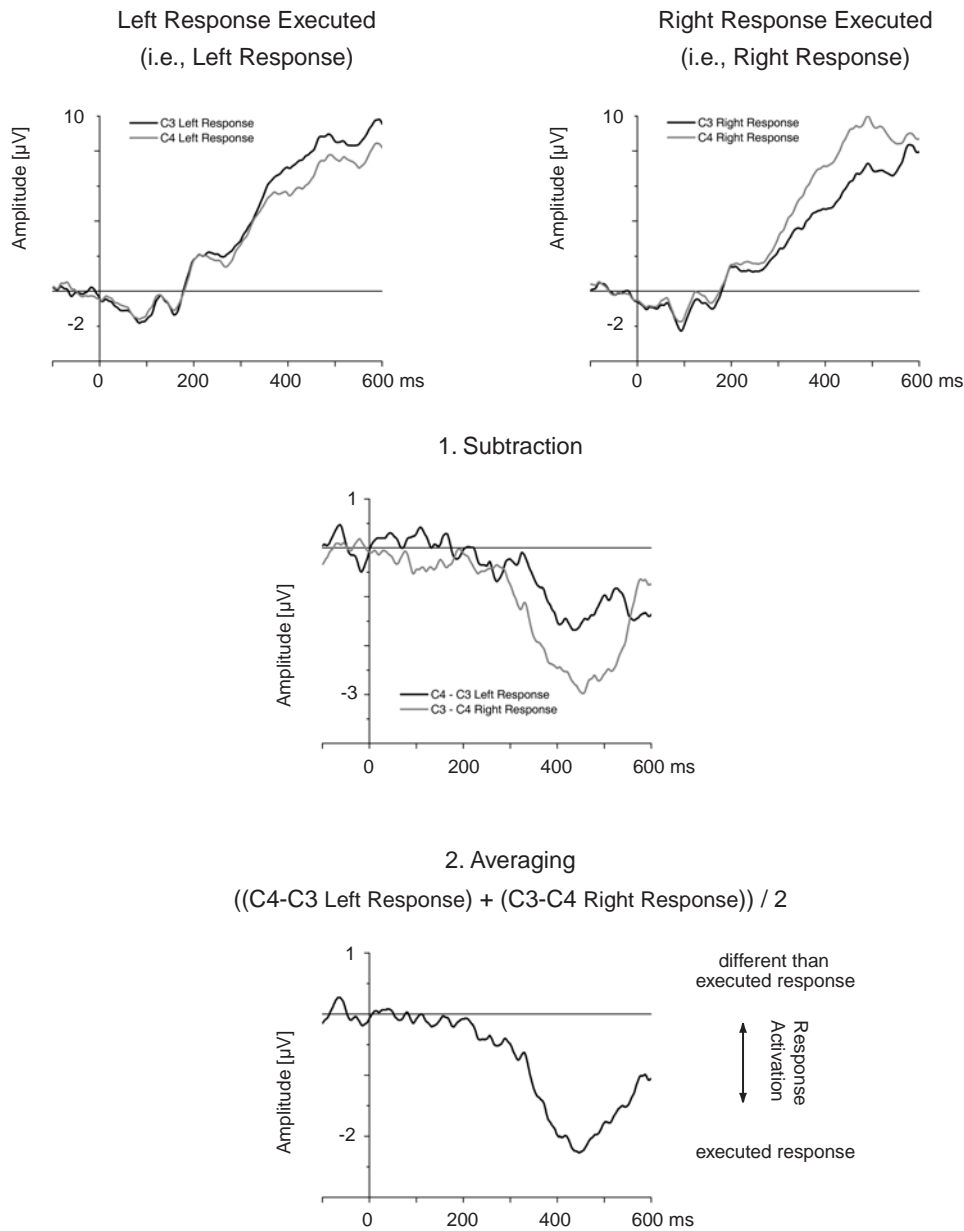


Figure 3.9: **Response-related computation of the lateralized readiness Potential (LRP) using the averaging method for the acquisition-consistent and -inconsistent trials of the free-choice test-phase.** **Top panels:** Possible waveforms elicited at C3 (an electrode positioned over the left motor cortex; black line) and C4 (an electrode positioned over the right motor cortex; gray line) elicited by left hand responses (left panel) and elicited by right hand responses (right panel). **Middle panel:** Difference waveform obtained by subtracting the waveform of C3 from C4 for the left hand responses (black line) and subtracting the waveform of C4 from C3 for the right hand responses (gray line). **Bottom panel:** The difference waveforms for the two response sides are averaged. For the resulting final LRP waveform negative (downward-going) deflections indicate activation of the executed response and positive (upward-going) deflections indicate activation of the alternative response (i.e., the response which was not executed). Here, an example of an acquisition-consistent trial is given.

3.2.3 Results

Five participants were excluded before further analyses because they either produced too many artifacts in the EEG (more than $> 30\%$ of all trials had to be removed; 4 participants) or due to technical errors during EEG recording (1 participant). This left 20 participants for further analyses.

Behavioral performance

Acquisition-phase

The square stimulus was produced on 50.5% [SE mean 1.2] and the diamond on 49.5% [SE mean 1.2] of the trials. The difference between these proportions was not significant ($t(19) = .45, p > .60$) indicating that the two action-effects were produced equally often.

Free-choice test-phase

For the Go-trials, the mean key-choice frequency and the mean RT was calculated for acquisition-phase consistent and acquisition-phase inconsistent key-choices. There were 50.0% [SE mean 1.0] acquisition-phase consistent and 50.0% [SE mean 1.0] acquisition-phase inconsistent key-presses ($t(19) = .002, p > .80$) and thus no indication of a prime-induced response bias. The false alarm rate for the NoGo-trials was 0.9%.

RT outliers (criterion described in the result of the forced-choice priming task of Experiment 1; 1.0% of all trials) were removed before further analyses. Acquisition-consistent responses were executed significantly faster than acquisition-inconsistent responses (473 ms [SE mean 11.4] and 484 ms [SE mean 11.8], respectively; $t(19) = 2.71, p < .02$).

Questionnaire

None of the subjects correctly identified the purpose of the task nor did any subject correctly report the shape of the primes. Again, as in Experiment 1 most participants did not notice the existence of the primes at all.

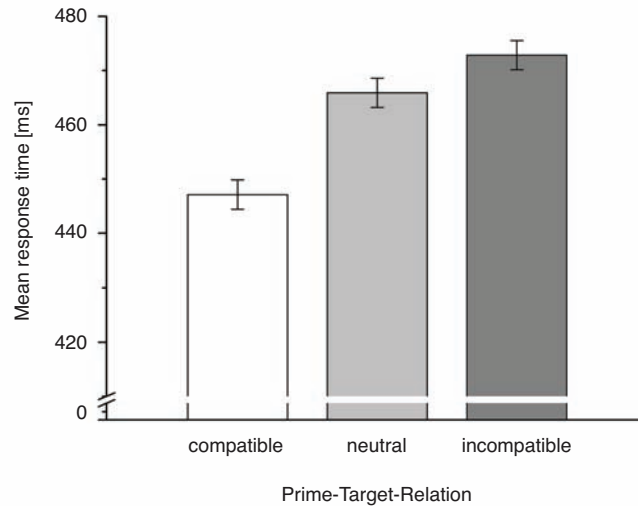


Figure 3.10: Mean correct response times (RTs) for compatible (white), neutral (light gray), and incompatible (dark gray) trials of the forced-choice priming task of Experiment 2. Error bars show 95 % within-subjects confidence intervals (Loftus & Masson, 1994).

Forced-choice priming task

The mean RTs for each condition (compatible, incompatible, neutral) are presented in Figure 3.10. RT outliers (criterion as described above, 1.8% of all trials) and trials on which a response error was made (1.3% of all trials) were removed from the data. An ANOVA with the factor response-compatibility (compatible, neutral, incompatible) revealed a significant main effect ($F(2,38) = 23.2$, $MSe = 152.7$, $p < .001$) which was due to significantly faster RTs on compatible (447 ms [SE mean 9.7]) as compared to neutral (466 ms [SE mean 7.6], $t(19) = 5.58$, $p < .001$) and incompatible (473 ms [SE mean 7.1], $t(19) = 5.05$, $p < .001$) trials. The neutral trials were significantly faster than the incompatible trials ($t(19) = 2.37$, $p < .03$).

The mean error rates for compatible, neutral, and incompatible trials were .92% [SE mean .22], 1.30% [SE mean .26] and 1.62% [SE mean .27], respectively. An ANOVA with the factor compatibility (compatible, neutral, incompatible) revealed a significant main effect ($F(2,38) = 9.367$, $MSe = .266$, $p < .001$). Significantly less errors were made on compatible than on incompatible ($t(19) = 3.9$, $p < .001$) and neutral ($t(19) = 3.14$, $p < .006$) trials.

Prime discrimination task

The primes were not identified above chance level. Participants correctly identified the primes on 46.5% [SE mean 2.6] of the trials and made an error on 53.5% [SE mean 2.6] of the trials ($t(19) = 1.36$, $p = .256$).

Electrophysiology*Free-choice test-phase*

Go- vs. NoGo-trials: Trials with artifacts in the EEG were removed before further analyses (6.2% of the Go-trials; 7.6% of the NoGo trials). To obtain a measure of prime-related response activation the LRP for the Go- and NoGo-trials was calculated depending on the response side the prime had been associated with during the acquisition-phase (prime-related calculation; see Figure 3.8, page 52). The LRP waveforms for the two trial types are presented in Figure 3.11 A. The LRP waveforms were divided into consecutive 50 ms time windows in the interval between prime-onset (0 ms) and 600 ms after prime-onset to statistically evaluate the time course of response activation. For each of the twelve time windows the mean amplitude was calculated. Figure 3.11 B presents the mean amplitude values for each time window.

A repeated measures ANOVA with the factors time window (1-12), and trial type (Go, NoGo) on the mean amplitude values revealed no significant main effects or interaction. To investigate if and when the waveforms of the Go- and NoGo-trials differed from the baseline (zero) two-tailed paired t-test were conducted on each of the mean amplitude values of each time window. The only significant effect for the Go-trials was obtained 200-250 ms after prime-onset where the average waveform was significantly more negative than zero ($t(19) = 2.56$, $p < .02$) indicating acquisition-consistent motor activity within this time window. The NoGo-trials did not differ significantly from zero within any of the time windows, although they approached significance 200-250 ms after prime-onset ($t(19) = 1.87$, $p < .08$). This result was due to the insignificant difference for the electrode pair C3/C4; the LRP waveform computed only for the electrode pair FC3/FC4 did differ significantly from the baseline ($p < .04$).

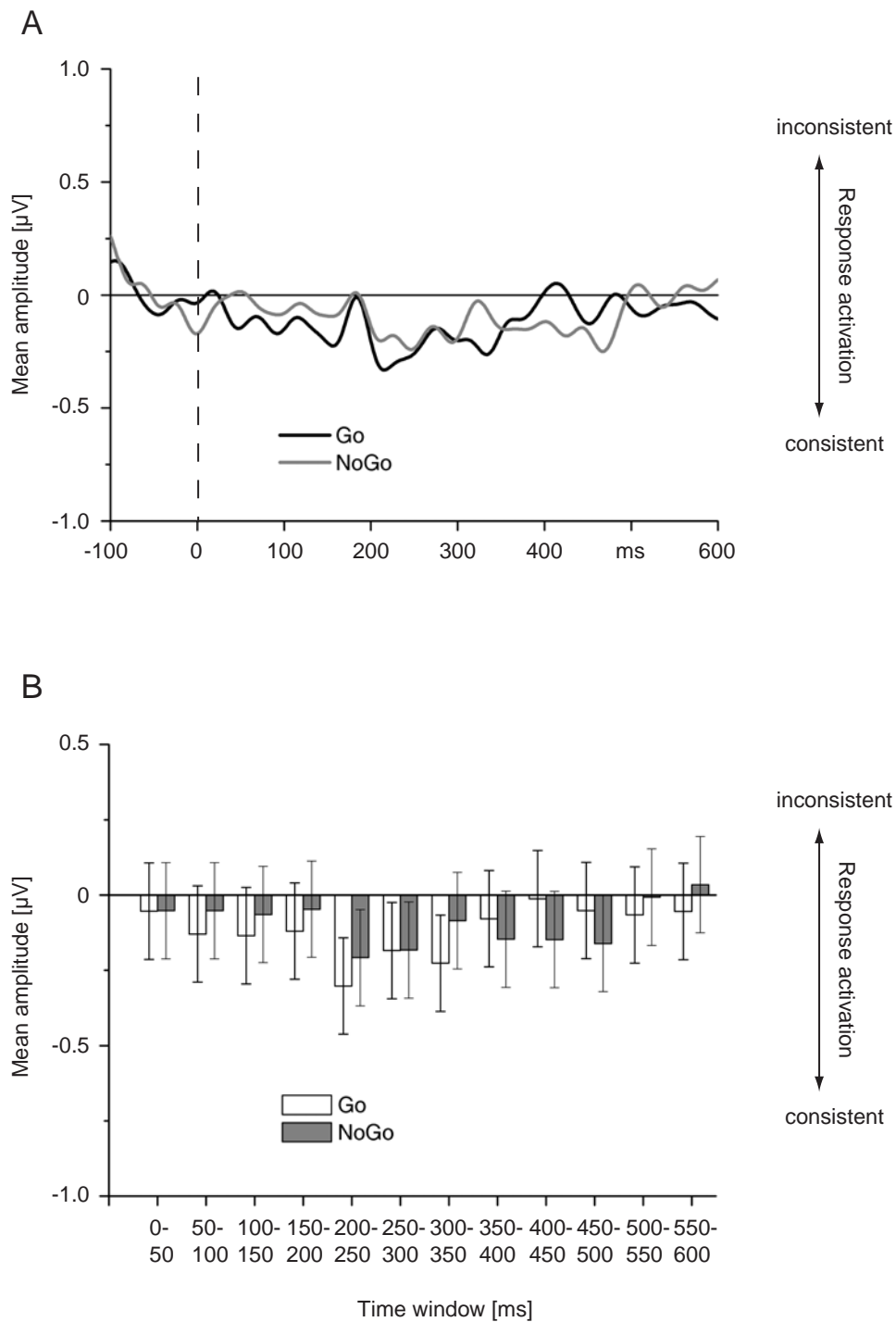


Figure 3.11: (A) Prime-related LRP waveform for the Go-trials (black) and NoGo-trials (gray) and (B) mean amplitude values of the separate time windows for the Go-trials (white) and NoGo-trials (gray) of the free-choice test-phase of Experiment 2. Negative values indicate acquisition(prime)-consistent response activation and positive values acquisition(prime)-inconsistent prime-induced response activation. Error bars show 95% within-subjects confidence intervals (Loftus & Masson, 1994).

Acquisition-consistent vs. acquisition-inconsistent Go-trials: For a follow-up analysis the Go-trials were split into trials on which acquisition-consistent or acquisition-inconsistent responses were chosen. The LRP was calculated response-related separately for the acquisition-consistent and -inconsistent trials (see Figure 3.9, page 53 and EEG data analysis section for details). The resulting LRP waveforms are presented in Figure 3.12 A. Again the waveforms were divided into twelve successive 50 ms time windows starting from prime-onset until 600 ms post-prime. The mean amplitude for each time window was calculated (Figure 3.12 B). An ANOVA with the factors time window (1-12) and consistency (acquisition-consistent choice, acquisition-inconsistent choice) was conducted. The main effect for time window reached significance due to overall increasing response activation of the finally executed response ($F(11,209) = 29.76$, $MSe = 1.34$, $p < .001$). The main effect of consistency also reached significance ($F(1,19) = 4.68$, $MSe = 1.89$, $p < .05$). There was a reliable difference between the acquisition-consistent and -inconsistent mean amplitude values 200-350 ms post-prime ($ts(19) > 2.0$, $ps < .05$). Within these time windows the LRP from the acquisition-consistent trials was significantly more negative than zero ($ts(19) > 2.8$, $ps < .02$) due to early acquisition-consistent response activation. The acquisition-consistent LRP continued to stay reliably more negative than zero for the remaining time windows due to the activation of the finally executed acquisition-consistent response ($ts(19) > 2.3$, $ps < .04$). By contrast, the LRP from the acquisition-inconsistent trials was only marginally more positive than the baseline 200-250 ms post-prime indicating borderline initial acquisition(prime)-consistent response activation (note that for the acquisition-inconsistent trials positive response activation indicates activation of the response *opposite* to the one which was chosen and therefore acquisition-consistent response activation). From approximately 300 ms onwards the LRP of the acquisition-inconsistent trials was more negative than baseline. At this time the activation of the final, acquisition-inconsistent, response started ($ts(19) > 3.6$, $ps < .003$). The interaction of time window-by-consistency failed significance ($F(11,209) = 1.43$, $MSe = .239$, $p > .10$).

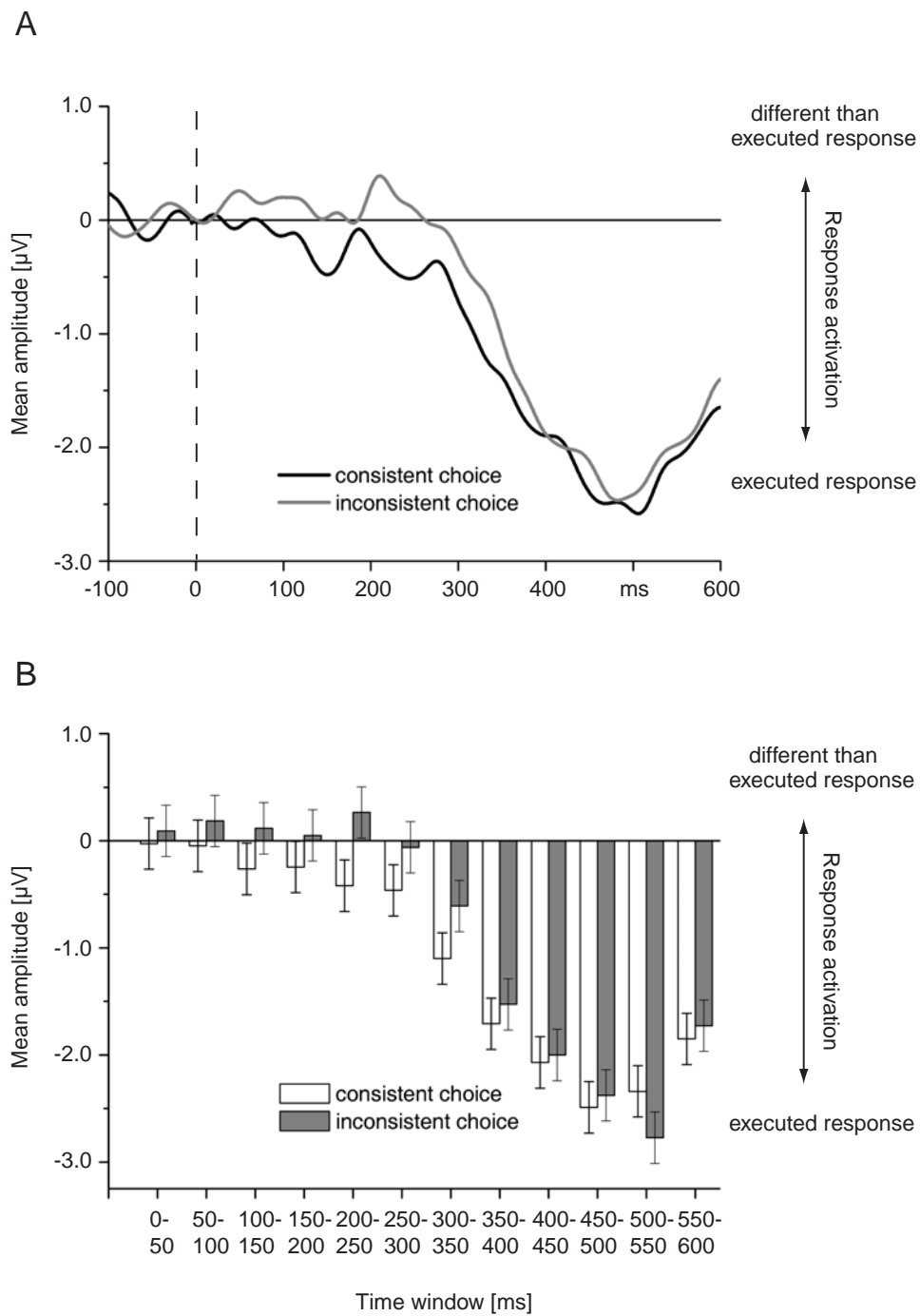


Figure 3.12: (A) Response-related LRP for the acquisition-consistent (black), and acquisition-inconsistent (gray) trials and (B) the mean amplitudes of the different time windows for acquisition-consistent (white) and acquisition-inconsistent (gray) trials of the free-choice test-phase of Experiment 2. Note that negative LRP deflections (amplitude values) indicate response-consistent and positive LRP deflections (amplitude values) response-inconsistent motor activation. Error bars show 95% within-subjects confidence intervals (Loftus & Masson, 1994).

Forced-choice priming task

Compatible vs. incompatible vs. neutral trials: Trials with artifacts were removed before further analysis (< 10% of all trials). Figure 3.13 A shows the response-related LRP waveforms obtained for the compatible, neutral, and incompatible priming condition (see 2.5, page 29 for details). Strong effects of prime-target compatibility are visible. The waveforms were divided into twelve time windows of 50 ms. The mean amplitudes within these time windows were calculated and are presented in Figure 3.13 B.

A repeated measures ANOVA with the factors time window (1-12), and compatibility (compatible, neutral, incompatible) yielded a significant main effect of time window ($F(11,209) = 33.60$, $MSe = 1.45$, $p < .001$) which was mainly due to more negative activity in later time windows because of the final activation of the correct response. The main effect of trial type failed significance ($F(2,38) = 2.55$, $MSe = 1.94$, $p < .09$). The time window-by-trial type interaction was highly significant ($F(22,418) = 3.35$, $MSe = .242$, $p < .00$). Planned comparisons showed that the waveforms of the compatible and incompatible conditions began to differ significantly from each other 200-250 ms after prime-onset ($t(19) = 2.88$, $p < .01$). In this time window the compatible waveform approached to be significantly more negative than zero ($t(19) = 1.92$, $p < .07$) indicating prime-consistent correct response activation. The incompatible waveform, however, was significantly more positive than zero suggesting an early activation of the incorrect response induced by the (incompatible) prime ($t(19) = 2.21$, $p < .04$). The compatible and incompatible waveforms continued to be significantly different from each other until 450 ms post-prime ($ts(19) > 2.0$, $ps < .05$). During the remaining time windows the compatible waveform was continuously significantly more negative than zero ($ts(19) > 2.2$, $ps < .04$) indicating target-related correct response activation. The incompatible waveform stayed significantly more positive than zero until approximately 300 ms after prime-onset ($t(19) = 2.52$, $p < .02$). Thereafter, it crossed the baseline and became significantly more negative than zero around 350 ms indicating target-related correct response activation ($ts(19) > 2.7$, $ps < .02$). The waveform of the neutral condition started to become more negative than zero around 250-300 ms after prime-onset and remained more negative throughout the remaining time windows ($ts(19) > 2.6$, $ps < .02$) due to correct response activation. The neutral and compatible waveforms never differed significantly from each other. The neutral wave-

form was significantly more negative than the incompatible waveform starting at around 250-350 ms post-prime ($ts(19) > 2.6$, $ps < .02$). This was also due to earlier target-related activation of the correct response on neutral trials as compared to incompatible trials.

Overall prime activity: To obtain a measure of overall prime-related response activation the compatible and incompatible trials were pooled and the prime-related LRP (see Figure 3.8, page 52) was calculated. The resulting LRP waveform is comparable to the waveforms of the Go- and NoGo-trials of the free-choice test-phase which were also calculated prime-related. It illustrates the amount to which the primes activated their mapped response, irrespective of the executed response. Neutral trials were not included in this analysis because the neutral prime was not mapped to any response and could therefore not induce any response processes. Figure 3.14 A shows the resulting LRP waveforms. The waveform was split into 50 ms time windows from 0-600 ms post-prime and the mean amplitude values were calculated (Figure 3.14 B). An ANOVA with the factor time window (1-12) yielded a significant main effect ($F(11,209) = 4.50$, $MSe = .167$, $p < .001$). This effect was due to reliable response activation by the primes starting around 200 ms after prime-onset and lasting for about 250 ms ($ts(19) > 2.2$, $ps < .04$). After 450 ms the waveform returned to the baseline because after a prime (e.g., the square) the target could either be response-compatible (e.g., also a square) or response-incompatible (e.g., the diamond). This setting lead to a cancellation of target-related response activity.

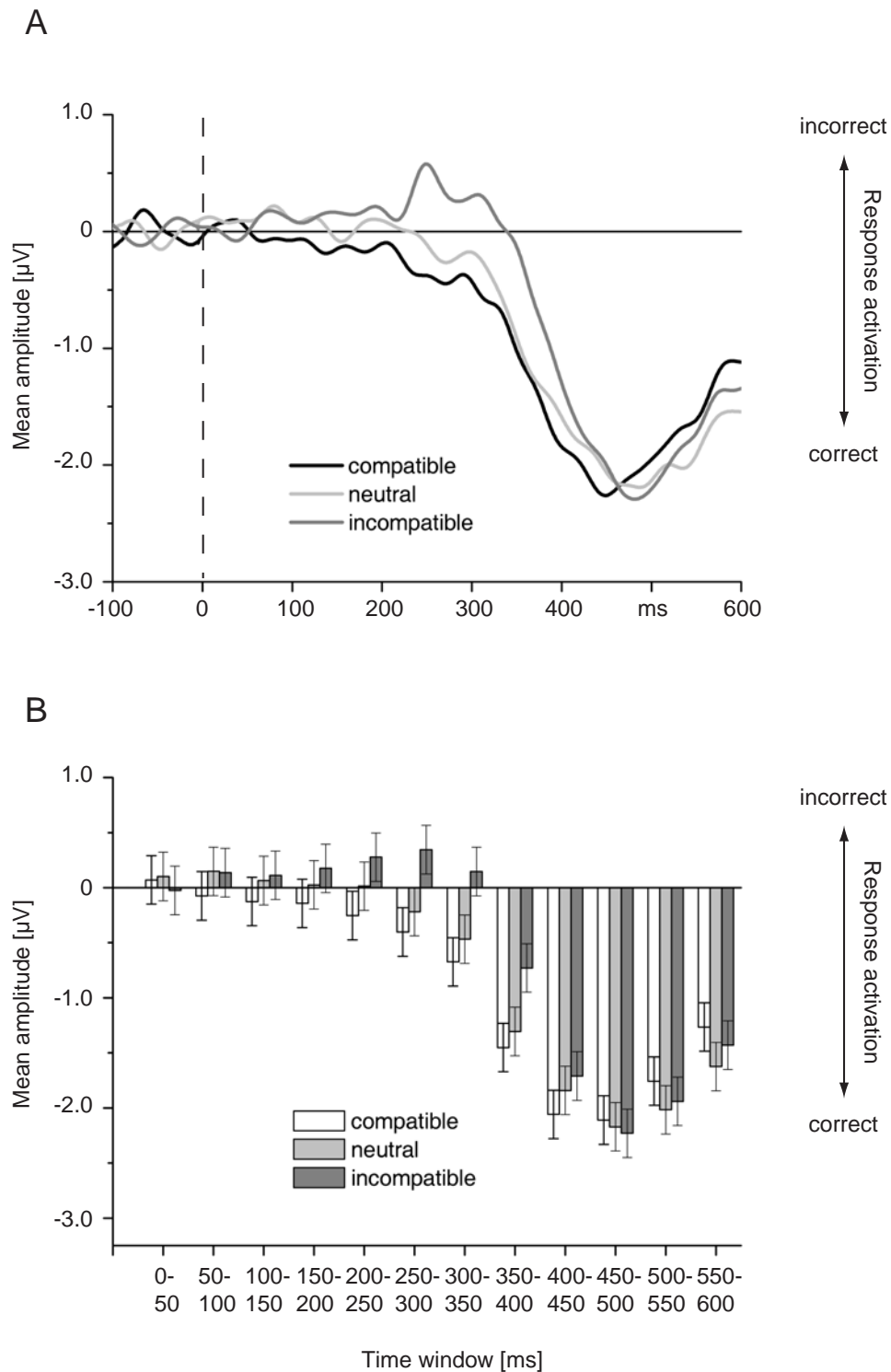


Figure 3.13: (A) Response-related LRP waveforms for compatible (black), neutral (light gray), and incompatible (dark gray), trials and (B) mean amplitudes of the LRP in different time windows for compatible (white), neutral (light gray), and incompatible (dark gray) trials in the forced-choice priming task of Experiment 2. Note that negative LRP deflections (values) indicate correct and positive LRP deflections (values) incorrect response activation (relative to the target stimulus). Error bars show 95% within-subjects confidence intervals (Loftus & Masson, 1994).

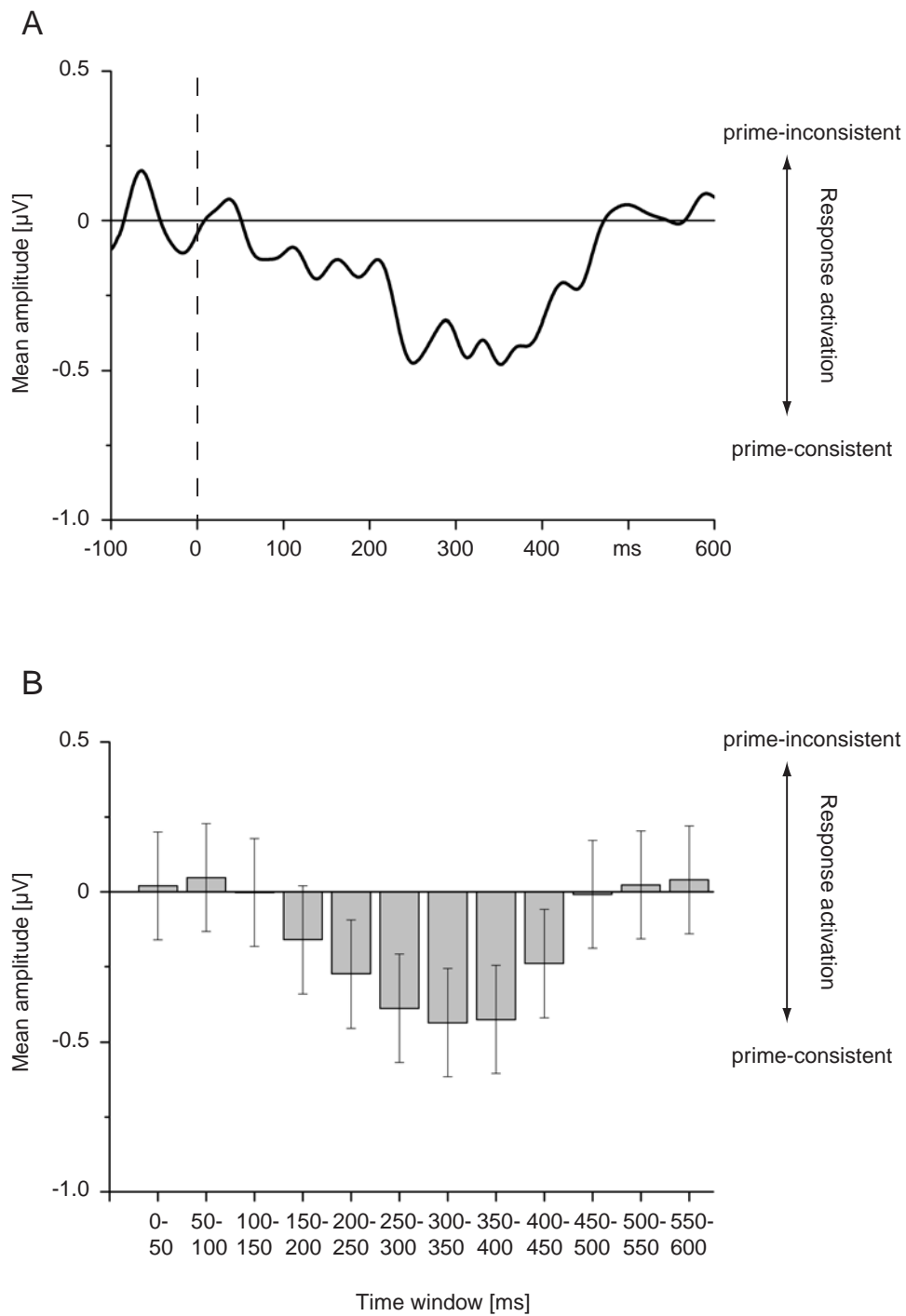


Figure 3.14: (A) Prime-related LRP waveform for averaged compatible and incompatible trials and (B) mean amplitudes for different time windows of the forced-choice priming task of Experiment 2. Note that negative LRP deflections (mean amplitude values) indicate prime-consistent and positive LRP deflections (mean amplitude values) prime-inconsistent motor activation. Error bars show 95% within-subjects confidence intervals (Loftus & Masson, 1994).

3.2.4 Discussion

In contrast to Experiment 1, the behavioral results of Experiment 2 did not suggest an influence of the unconscious effect-primers on the response-choice. No response bias in the sense of more acquisition-phase consistent than -inconsistent key-choices was obtained in the free-choice test-phase. One likely explanation for the missing bias is the nature of the Go/NoGo-paradigm. In the test-phase of Experiment 1, participants could press any of the two possible response keys as soon as the Go-signal appeared without further elaborate processing of the imperative stimulus. Thus, responses were executed very fast as manifest in mean RTs around 200 ms. In contrast, in the Go/NoGo- test-phase of Experiment 2 the imperative stimulus had to be processed in more detail in order to decide whether a response had to be executed or withheld. This additional processing time became evident in longer RTs to the Go-signal. This additional top-down (intentional) process might have weakened the influence of automatic, bottom-up processes (i.e., prime-related response activation), especially if the partial response activation induced by the effect-primers was not very strong.

Importantly, the LRP data clearly revealed that the effect-primers did indeed activated their associated motor codes. This became evident in reliable prime-induced acquisition-consistent response activation starting at around 200 ms after prime-onset in the Go-trials of the free-choice test-phase. Additionally, different time courses of response activation could be observed for acquisition-consistent and -inconsistent trials. In the acquisition-phase consistent trials substantial prime-induced acquisition-consistent response activation started at about 200 ms after prime-onset and continuously increased until the acquisition-consistent response was executed. In the acquisition-inconsistent trials, on the other hand, an initial (about 200 ms after prime-onset) activation of the response opposite to the one finally executed was visible (i.e., an acquisition-*consistent* response activation). This activation was reversed after about 50 ms into activation of the actually executed (acquisition-*inconsistent*) response. This means that there was an early prime-induced activation of the acquisition-*consistent* response on both the acquisition-consistent as well as the acquisition-inconsistent trials, which was however smaller in amplitude (i.e., weaker) for the acquisition-inconsistent trials. What could lead to the re-

versal of response activation in the acquisition-inconsistent trials? One possibility is that the perception and processing of the prime stimulus was not equally strong on all trials. The mean amplitude of the LRP in the crucial time window of the LRP was, as mentioned above, on a descriptive level smaller on acquisition-inconsistent than on consistent trials. One possibility could therefore be that on trials where the priming effect was weak (and partial response activation was small) the probability of choosing the non-associated (i.e., inconsistent) response was higher relative to trials with strong prime-induced response activation. Conversely, on trials on which prime-induced response activation was stronger there was presumably also a stronger bias to choose the acquisition-consistent response. Further, the RT data obtained from the free-choice test-phase revealed shorter RTs for acquisition-consistent trials. Consistent with the interpretation outlined above, this finding suggests that on trials where prime-induced motor activation was strong this activation led to a faster (immediate) execution of the primed response (at least on a large proportion of trials). By contrast, on trials with less prime-induced motor activity the smaller bias to choose the acquisition-consistent response presumably also delayed the final choice and thus resulted in longer RTs. There was also a borderline reliable effect of prime-related acquisition-consistent response activation on the NoGo-trials. The smaller amplitude of the effect for NoGo- as compared to Go-trials could be due to overall weaker response activation on NoGo-trials (presumably due to fast inhibition of response activation processes after the appearance of the NoGo-signal).

Taken together, the results of the test-phase of Experiment 2 indicate that the unconscious presentation of former action-effects automatically activates associated motor codes. The chance level performance in the prime discrimination task again show that the primes were indeed not consciously perceived. Further, the results of the forced-choice priming task suggest that the prime-stimuli could generally influence behavior in the expected direction (shorter RTs on compatible as compared to incompatible and neutral trials) and that they reliably induce motor activity (as evident in initial prime-induced response activation in the LRP). Interesting in this context is, that the size of the prime-induced response activation by the effect-primes in the test-phase was equal to that induced by the primes in the forced-choice priming task. This shows that both response association types (the R-E association in the acquisition-phase which was responsible for the priming effect

in the test-phase and the S-R mapping from the forced-choice priming task) had equally strong effects on response selection processes. One interesting question concerns the time course of the response priming effect. It has been shown in forced-choice priming experiments, that partial response activation by masked primes may subsequently reverse into inhibition of the primed response (Eimer & Schlaghecken, 1998; Klapp & Hinkley, 2002; see 2.3.2, page 20 for details on the activation-followed-by-inhibition hypothesis). Such an inhibitory mechanism may also be functionally relevant in the context of automatic response activation by unconscious effect features. Such an automatic response activation might be helpful in situations where the activated response is the one, which most likely has to be carried out. However, it is also necessary to inhibit such automatic response tendencies, especially when a sudden change in the environment requires an instant modification of one's response tendencies or if response tendencies have been activated that are inappropriate in a given context. To investigate how response activation induced by unconscious effect features develops over time, Experiment 3 was conducted.

3.3 Experiment 3: The time course of unconscious response priming by action-effects

3.3.1 Introduction

Although the LRP results of Experiment 2 clearly indicate that unconsciously presented action-effects can activate associated motor codes the results also raise some questions which remain to be answered. In particular, a further experiment using the LRP as an indicator of response activation was conducted in order to investigate the time course of response-priming induced by action-effects. Specifically, the question was whether masked effect-primes may under certain conditions also lead to inhibition of associated motor responses, similar to the negative compatibility effect (NCE) that has been observed in forced-choice tasks (see 2.3.2, page 20 for details on the NCE). Eimer and Schlaghecken (1998; see 2.3 for details) have shown that unconscious primes activate responses which have been mapped to them in the instruction. However, if the time between prime-onset and target-onset is sufficiently long the initial response activation appears to be automatically inhibited. This activation-followed-by-inhibition process resulted in shorter RTs on

incompatible trials (i.e., if prime and target were mapped to different responses) relative to compatible trials and was importantly also visible in the LRP, suggesting that it was indeed motor activation and inhibition which lead to the behavioral results. Interestingly, inhibition was induced only if the primes were presented subliminally. Consciously perceivable primes did not produce the pattern of results (Eimer & Schlaghecken, 2002). Since the effect-primes in the present experiments were also presented unconsciously it is fair to assume that the initial response activation induced by the effect-primes is inhibited if the time between prime-onset and Go-signal-onset is increased. To test this hypothesis, Experiment 3 was conducted.

In Experiment 3 a similar design as in Experiment 1 and 2 was used. Importantly, the time between the onset of the prime and the appearance of the Go-signal in the free-choice test-phase was increased. If, as expected, the effect-primes activate the responses associated with them, this activation should again be evident around 200 ms after prime-onset. However, due to the longer time interval until the key-choice the initial response activation should return to a baseline level or even reverse into inhibition of the response associated with the effect-prime (Eimer & Schlaghecken, 1998). As a consequence, with a longer prime - Go-signal SOA no or even a reversed response bias should be visible in the free-choice key-presses in the test-phase. The stimuli used in Experiment 3 differed from that of the former two experiments because the mask used in Experiment 1 and 2 might have influenced the results in the free-choice test-phase in a unintended way. As the mask in these experiments consisted of a superimposition of the two effect-stimuli it included features, which had been associated with different responses in the acquisition-phase. This could be problematic if the prime - Go-signal SOA is increased. If the effect-primes activate the response associated with them, the mask, which follows the prime in close temporal succession, could partially activated the response associated with the other stimulus (e.g., if a square is presented as effect-prime and partially activates its associated response [e.g., left], the mask could lead to an activation of response associated with the diamond [e.g., right]; Lleras & Enns, 2004; see 2.3.2, page 20 for details on the object-substitution hypothesis and the NCE). In order to exclude this alternative explanation, a new mask was used to reduce the possibility of unwanted response activation by the mask. In the forced-choice priming task, where the prime - target SOA was also increased, RTs should

be shortest on incompatible as compared to compatible and neutral trials due to response inhibition processes (see 2.3.2, page 20 for a description of the NCE). Correspondingly, reliable inhibition of the primed responses should be visible in the LRP from the compatible and incompatible conditions. Experiment 3, like the first two experiments, consisted of four experimental parts which were conducted in succession (acquisition-phase, free-choice test-phase (questionnaire), prime discrimination phase and forced-choice priming task). The EEG was recorded during the test-phase and the forced-choice priming task.

3.3.2 Method

Participants

Twenty-six naïve volunteers (students from the Dresden University of Technology; age 18-28, mean age 22.6; 15 female; all right-handed) participated in Experiment 3. All of them had normal or corrected to normal vision and reported no history of neurological or psychiatric disorders. They either received course credit or were paid Euro 5 per hour for their participation.

Stimuli, procedure, and design

Acquisition-phase

The stimuli used in the acquisition-phase of Experiment 3 are shown in Figure 3.15. They extended 4 cm in width and height (1.75° visual angle). The procedure and design of the acquisition-phase was identical to the acquisition-phases of Experiments 1 and 2.

Free-choice test-phase

The stimuli and timing of the test-phase of Experiment 3 are shown in Figure 3.16. The prime stimuli extended 2 cm in width and height (1.20° visual angle). The mask stimulus extended 4 cm in width and height (1.75° visual angle). The cross used as a Go-signal extended 3 cm and the # sign (NoGo-signal) 3.2 cm. The procedure and design of the free-choice test-phase was almost identical to that of Experiment 2. The only differences were the duration of the mask, which was now presented for 100 ms and the number of trials (336 Go- and 336 NoGo-trials). The test-phase consisted of 12 blocks with 56 trials each. 10 practice trials were administered prior to the beginning of the main task.

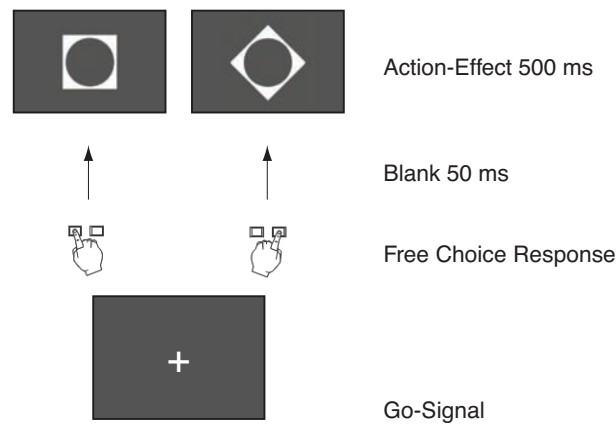


Figure 3.15: Sequence of events on a trial of the acquisition-phase of Experiment 3.

Questionnaire

After the free-choice test-phase participants filled out a short questionnaire to investigate whether they were subjectively able to identify the prime-stimuli (see appendix C).

Forced-choice priming task

The primes used in the forced-choice priming task were the same as in the free-choice test-phase (see Figure 3.16, 70). Additionally, a third (neutral) prime was introduced. This neutral prime was a superimposition of the two effect-prime stimuli and extended 1.20° of visual angle. The effect stimuli from the acquisition-phase served as targets in the forced choice priming task. The only differences in the procedure and design as compared to Experiment 2 were that the mask was presented for 100 ms and that there were 480 trials overall (160 compatible, 160 neutral, 160 incompatible). The task was divided into 8 experimental blocks (60 trials each, 20 practice trials).

Prime discrimination task

The primes and the Go-signal were the same as in the free-choice test-phase (see Figure 3.16). The timing of the prime discrimination task was also identical to the test-phase. The only difference in the procedure was that participants were asked to indicate which stimulus (diamond or square) appeared prior to the mask. The task consisted of 200 trials (each prime was presented 100 times) and was divided into 4 experimental blocks (50 trials each). Before the first experimental blocks a practice block of 10 trials was given.

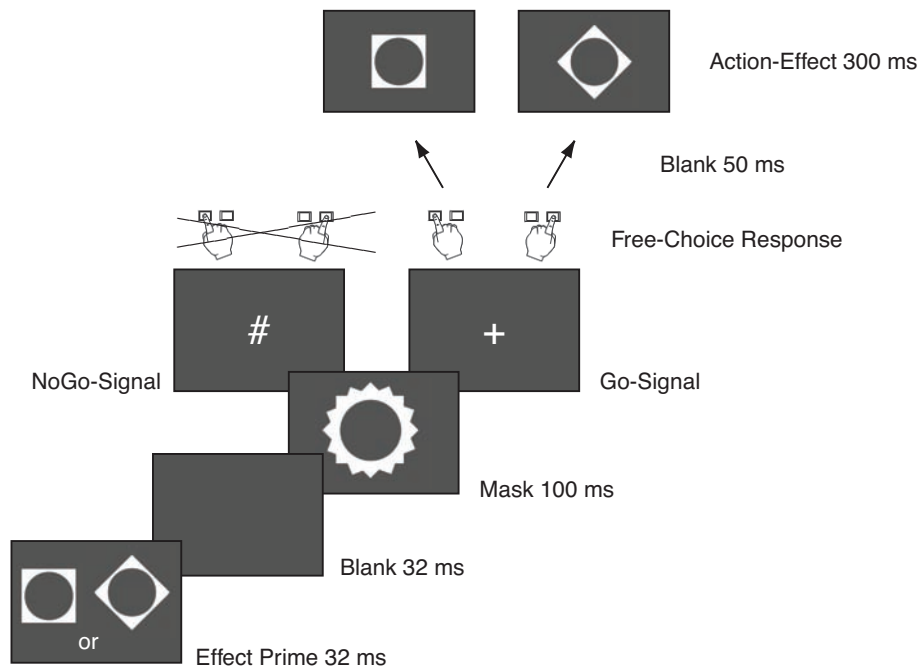


Figure 3.16: Sequence of events on a trial of the free-choice test-phase of Experiment 3.

EEG data acquisition and analysis

The EEG was recorded during the test-phase and the forced choice priming task. The recording setting differed from that in Experiment 2 only in the number and location of recording sites. Fifteen Ag/AgCl electrodes were used to derive the EEG (F3, Fz, F4, FC3, FC1, FC2, FC4, C3, C1, Cz, C2, C4, P7, Pz, P8; see Figure 3.7, page 49 for the location of the electrode sites on the scalp). The sampling rate was 1000 Hz. The amplifier had a high cut-off of 250 Hz and a time-constant of 10 s (low cut-off = 0.016 Hz). The software-filters were set to high cut-off of 80 Hz. A notch-filter (50 Hz) was applied. All impedances were kept below 5 k Ω throughout the experiment. EEG analysis, i.e., segmentation, baseline correction, artifact rejection, and LRP calculation methods were equivalent to those of Experiment 2 (see 3.2.2, page 48).

The Experiment started with the acquisition-phase followed by the test-phase, the forced-choice priming task, and the prime discrimination task. It took about 2.5 hours to complete the entire experiment.

3.3.3 Results

Behavioral performance

Three subjects had to be excluded due to a large number of artifacts in the data (>30% of the trials). The following analyses (for the behavioral and electrophysiological data) were performed on data from the remaining 23 subjects.

Acquisition-phase

The two frequencies with which the two effect stimuli were produced were almost identical and did not differ significantly (50.9% [SE mean 1.6] and 49.1% [SE mean 1.6]; $t(22) = .586$, $p > .70$).

Free-choice test-phase

For the Go-trials, the mean key-choice frequency and the mean RT was calculated for acquisition-phase consistent and acquisition-phase inconsistent key-choices. The acquisition-consistent key was chosen on 50.1% [SE mean 0.7] and the acquisition-inconsistent key on 49.9% [SE mean 0.7] of all Go-trials. These frequencies did not differ significantly from chance ($t(22) = .135$, $p > .88$). There was thus no prime-induced response bias.

RT outliers (criterion described in the result of the forced-choice priming task of Experiment 1; 1.3% of all trials) were removed before further RT analyses. Mean RTs for acquisition-consistent (492 ms [SE mean 23]) and acquisition-inconsistent (502 ms [SE mean 23]) trials did not differ significantly ($t(22) = 1.02$, $p > .30$). The false alarm rate on NoGo-trials was 2.9%.

Questionnaire

Again, none of the subjects correctly identified the purpose of the task nor did any subject correctly report the shape of the primes.

Forced-choice priming task

The mean correct RTs for the compatible, neutral, and incompatible trials are presented in Figure 3.17. RT outliers (RTs below 200 ms and above 2000 ms and RTs on which

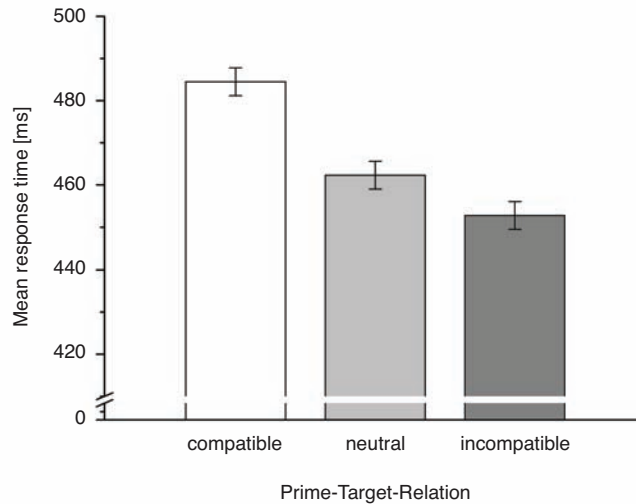


Figure 3.17: Mean correct response times (RTs) for compatible (white), neutral (light gray), and incompatible (dark gray) trials of the forced-choice priming task of Experiment 3. Error bars show 95 % within-subjects confidence intervals (Loftus & Masson, 1994).

the score deviated from the mean score for that experimental condition with an absolute value for $z > 2.5$, 1.8% of all trials) and trials on which a response error was made (1.4% of all trials) were excluded before further analysis. A repeated measures ANOVA with the factor compatibility (compatible, neutral, incompatible) performed on the remaining RTs revealed a significant main effect ($F(2,44) = 24.72$, $MSe = 246.39$, $p < .001$).

This effect was due to significantly shorter RTs on compatible as compared to neutral and incompatible trials ($ts(22) > 5.72$, $ps < .001$, RTs were 485 ms [SE mean 27], 465 ms [SE mean 27], and 452 ms [31] for the compatible, neutral, and incompatible condition, respectively). The corresponding ANOVA on the error rates also yielded a significant main effect of compatibility ($F(2,44) = 26.48$, $MSe = .423$, $p < .001$). Participants made significantly more errors on compatible (2.1% [SE mean .29]) as compared to neutral (1.4% [SE mean .90]) and incompatible trials (.74% [SE mean .16]; $ts(22) > 4.36$, $ps < .001$).

Prime discrimination task

The hit rate (i.e., proportion of correctly identified primes) in the prime discrimination task was 51.4% [SE mean 1.3] did not differ significantly different from chance ($t(22) = 1.084$, $p > .20$) indicating that the primes were not consciously identified.

Electrophysiology

Free-choice test-phase

Go- vs. NoGo-trials: A first analysis was conducted on the Go- and NoGo-trials separately. This was again done to examine the overall influence of the primes (i.e., whether they induced response activation). Go-trials with artifacts and with RTs exceeding 1200 ms (measure from the onset of the Go-signal) were excluded before further analyses (2.4%). NoGo-trials with artifacts and mistaken response execution were removed (5.8%). The prime-related LRP (see Figure 3.8, page 52) was calculated for both the Go- and NoGo-trials. Figure 3.18 A presents the resulting LRP waveforms.

As in Experiment 2, the waveforms were divided into twelve successive time windows of 50 ms starting from 0 to 600 ms post-prime for statistical analysis. The mean amplitude values in the different time windows were calculated (Figure 3.18 B). An ANOVA with the factors time window (1-12) and trial type (Go, NoGo) revealed a significant main effect of time window ($F(11,242) = 1.88$, $MSe = .066$, $p < .05$). The main effect of trial type failed to reach significance ($p > 1$), as did the interaction ($F(11,242) = 1.50$, $MSe = .061$, $p > .2$). Separate two-tailed paired t-tests showed that the Go- and NoGo-trials did not differ significantly from each other in any of the twelve time windows. Importantly, 150-200 ms post-prime the Go-trials were significantly more negative than zero indicating prime-induced acquisition-consistent response activation ($t(22) = 2.4$, $p < .03$). The NoGo-trials never differed significantly from the baseline.

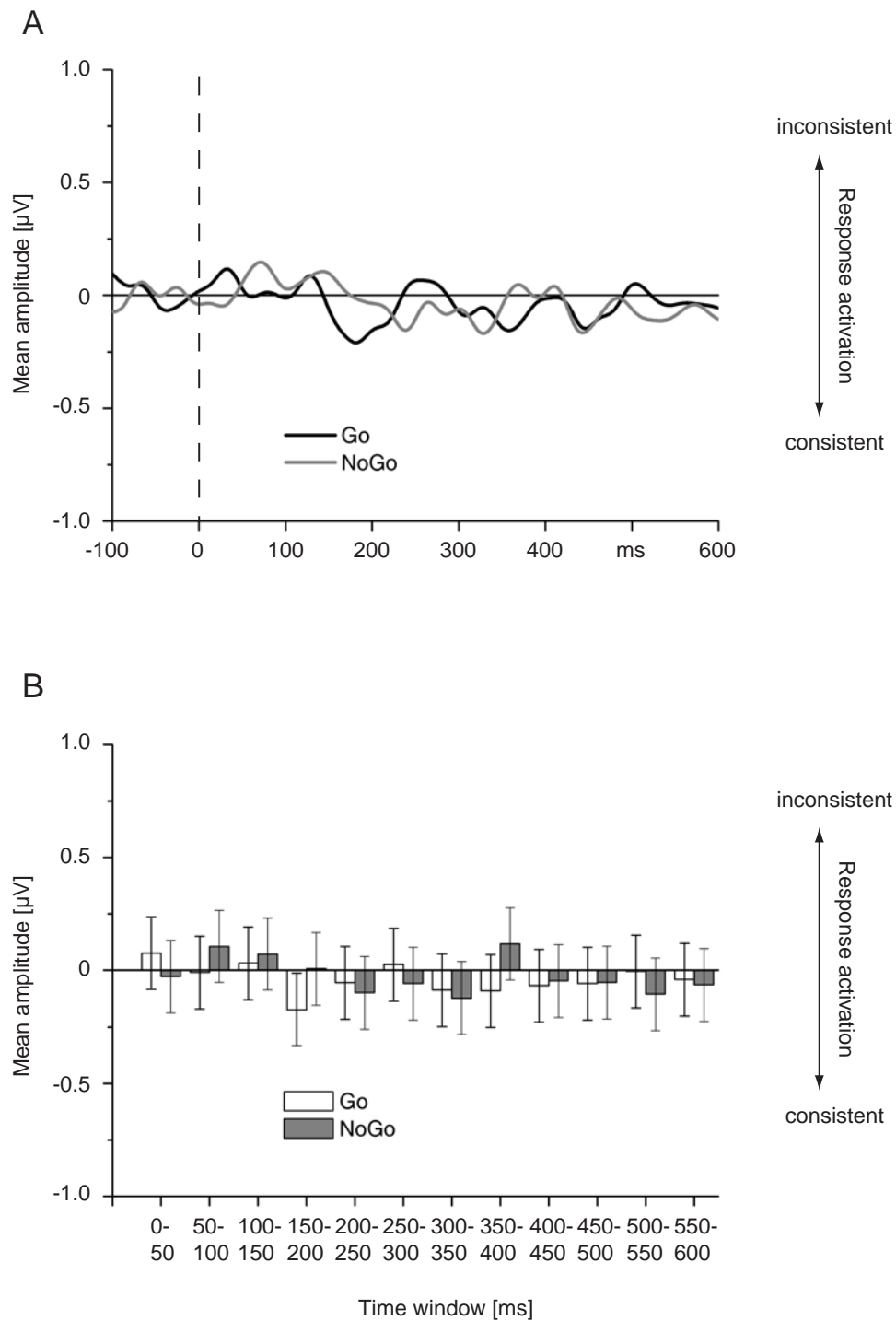


Figure 3.18: (A) Prime-related LRP for the Go-trials (black) and NoGo-trials (gray) and (B) mean amplitudes in the different time windows for the Go-trials (white) and NoGo-trials (gray) of the free-choice test-phase of Experiment 3. Note that negative LRP deflections (values) indicate acquisition-consistent and positive LRP deflections (values) acquisition-inconsistent response activation. Error bars show 95 % within-subjects confidence intervals (Loftus & Masson, 1994).

Acquisition-consistent vs. acquisition-inconsistent trials: In a next step the response-related LRP waveforms were computed separately for acquisition-consistent and -inconsistent Go-trials (see Figure 3.9, page 53 and the EEG data analysis section of Experiment 2 for details). Figure 3.19 A shows the LRP waveforms obtained for the acquisition-consistent and acquisition-inconsistent conditions. The waveforms were divided into twelve successive 50 ms time windows (0-600 ms post-prime) and the mean amplitude within these different time windows was calculated (3.19 B). An repeated-measures ANOVA with the factors time window (1-12), and consistency (consistent, inconsistent) revealed a significant main effect of time window ($F(11,242) = 43.56$, $MS_e = .506$, $p < .001$) as well as a significant interaction ($F(11,242) = 2.29$, $MS_e = .114$, $p < .02$). The main effect of consistency failed significance ($F(1,22) = .495$, $MS_e = 1.07$, $p > .40$). Two-tailed paired t-tests showed that the LRPs from the acquisition-consistent and - inconsistent trials differed significantly from each other 150-200 ms after prime-onset ($t(22) = 2.5$, $p < .02$). Within this time window the acquisition-consistent LRP was significantly more negative than zero indicating early prime-induced acquisition-consistent response activation ($t(22) = 2.5$, $p < .03$). From 200-300 ms post-prime the acquisition-consistent LRP was not different from baseline. At about 300 ms the activation of the finally executed acquisition-consistent response started ($ts(22) > 2.1$, $ps < .04$). The acquisition-inconsistent LRP was significantly more negative than the baseline 100-150 ms post-prime ($t(22) = 2.48$, $p < .03$) and from 350 ms onwards indicating the activation of the finally executed acquisition-inconsistent response ($ts(22) > 2.4$, $ps < .03$).

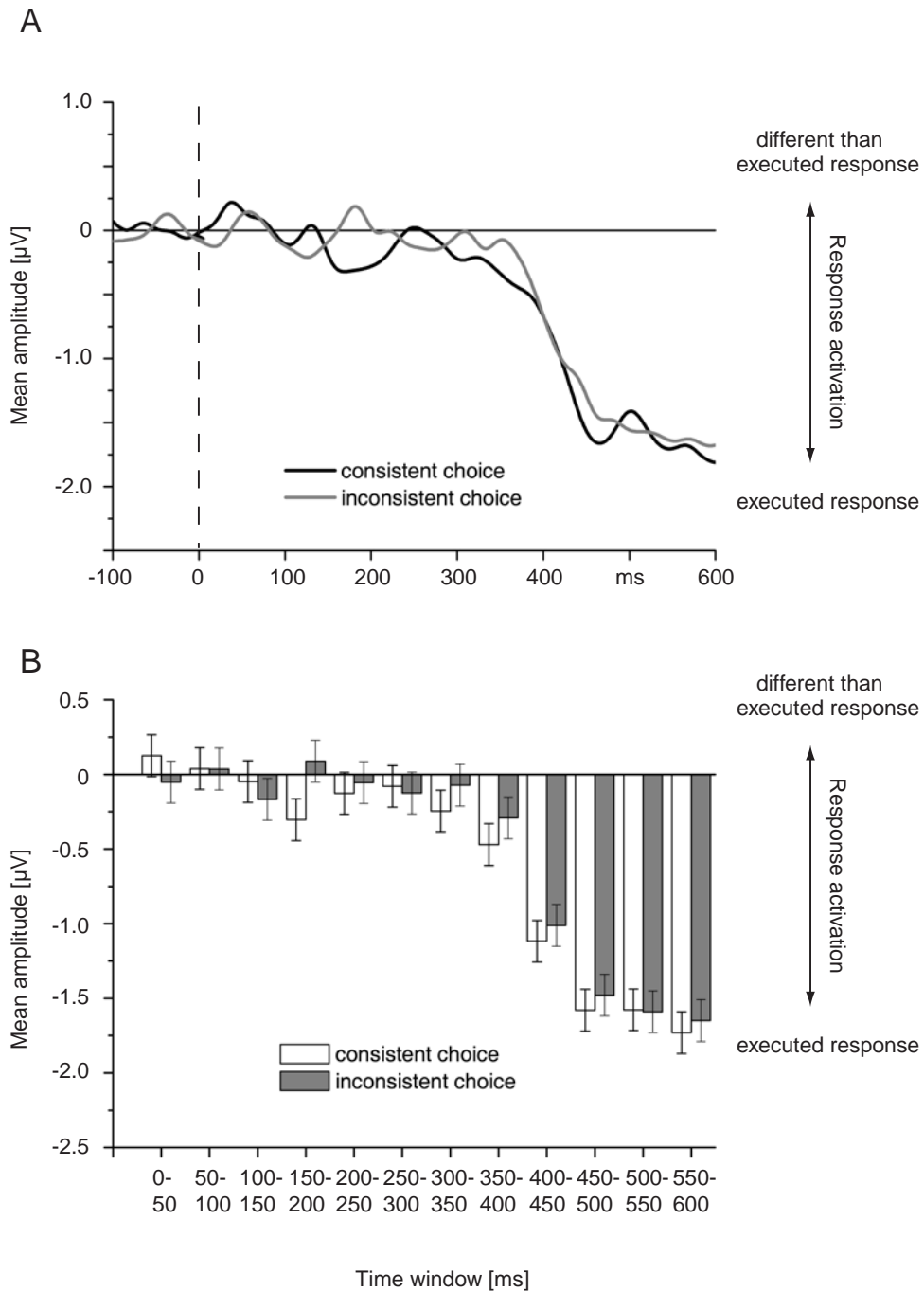


Figure 3.19: (A) Response-related LRP waveforms for acquisition-consistent (black) and acquisition-inconsistent (gray) key-choices and (B) mean amplitude in different time windows for acquisition-consistent (white) and -inconsistent (gray) trials within the Go-trials of the free-choice test-phase of Experiment 3. Note that negative deflections (values) indicate response-consistent response activation and positive deflections (values) response-inconsistent response activation. Error bars show 95 % within-subjects confidence intervals (Loftus & Masson, 1994).

Forced-choice priming task

Compatible vs. neutral vs. incompatible trials: Trials with artifacts were excluded before further analyses (< 10% of all trials). The response-related LRP waveforms for the compatible, incompatible, and neutral condition of the forced-choice priming task are shown in Figure 3.20 A (see 2.5, page 29 for LRP calculation). The waveforms were divided into twelve successive 50 ms time windows and the mean amplitude of the different time windows was calculated separately for each condition (Figure 3.20 B).

An ANOVA on the mean amplitude values from the time windows with the factors time window (1-12), and compatibility (compatible, neutral, incompatible) revealed a significant main effect of time window ($F(11,242) = 46.29$, $MS_e = .744$, $p < .001$). The main effect of compatibility failed significance ($F(2,44) = 2.217$, $MS_e = 1.296$, $p > .10$). Clear differences between the LRP waveforms were visible and became evident in a significant interaction ($F(22,484) = 4.262$, $MS_e = .235$, $p < .001$). Planned comparisons showed that the LRP waveforms from the compatible and incompatible trials first differed significantly from each other 150-300 ms post-prime ($ts(22) > 2.10$, $ps < .04$). 250-300 ms post-prime the compatible LRP waveform was significantly more negative than zero ($t(22) = 2.37$, $p < .03$) indicating prime-induced correct response activation whereas the incompatible waveform approached to be significantly more positive than zero from 150-300 ms post-prime (i.e., in the direction of incorrect response activation; $ts(22) > 1.97$, $ps < .07$). Around 400 ms post-prime the incompatible LRP started to become more negative than the baseline due to final correct response activation after the appearance of the target ($ts(22) > 4.64$, $ps < .001$). The compatible waveform returned to the baseline 300-450 ms post-prime and again started to be more negative from 450 ms onwards indicating target-induced correct response activation ($ts(22) > 4.68$, $ps < .001$). The compatible and neutral LRP waveforms only differed significantly from each other from 400-450 ms ($t(22) = 3.48$, $ps < .002$). During this time window the neutral waveform was more negative than the baseline because final target-related response activation had already started on neutral trials ($t(22) = 1.90$, $p < .06$) as compared to compatible trials. The neutral and incompatible LRP differed significantly from 150-350 ms ($ts(22) > 2.27$, $ps < .03$). During this time the incompatible LRP was more positive due to initial incorrect prime-induced response activation whereas no prime-induced response activity was evident for neutral trials ($ps > .10$).

Overall prime activity: To obtain a measure of overall response activation elicited by the primes the prime-related LRP (see Figure 3.8, page 52 for details) was calculated, averaging across compatible and incompatible trials (neutral trials were not included because they were not mapped to any response and should therefore not induce any response activity). The resulting waveform is presented in Figure 3.21 A. The waveform was divided into twelve 50 ms time windows and the mean amplitude for each time window was calculated (Figure 3.21 B). An ANOVA on the mean amplitude values with the factor time window (1-12) yielded a significant main effect ($F(11,242) = 7.47$, $MSe = .140$, $p < .001$). Planned comparisons (two-sided t-tests) revealed significant prime-consistent response activation in the time windows 150-300 ms after prime-onset ($ts(22) > 2.0$, $ps < .05$). In later time windows (350-450 ms) the effect reversed ($ts(22) > 2.6$, $ps < .02$) resulting in reliable prime-inconsistent response activation. This result shows that the primes first activated the response mapped to them. However, after some time this response activation reversed (due to inhibition of the activated response) and response activation opposite to that associated with the prime (prime-inconsistent) is evident.

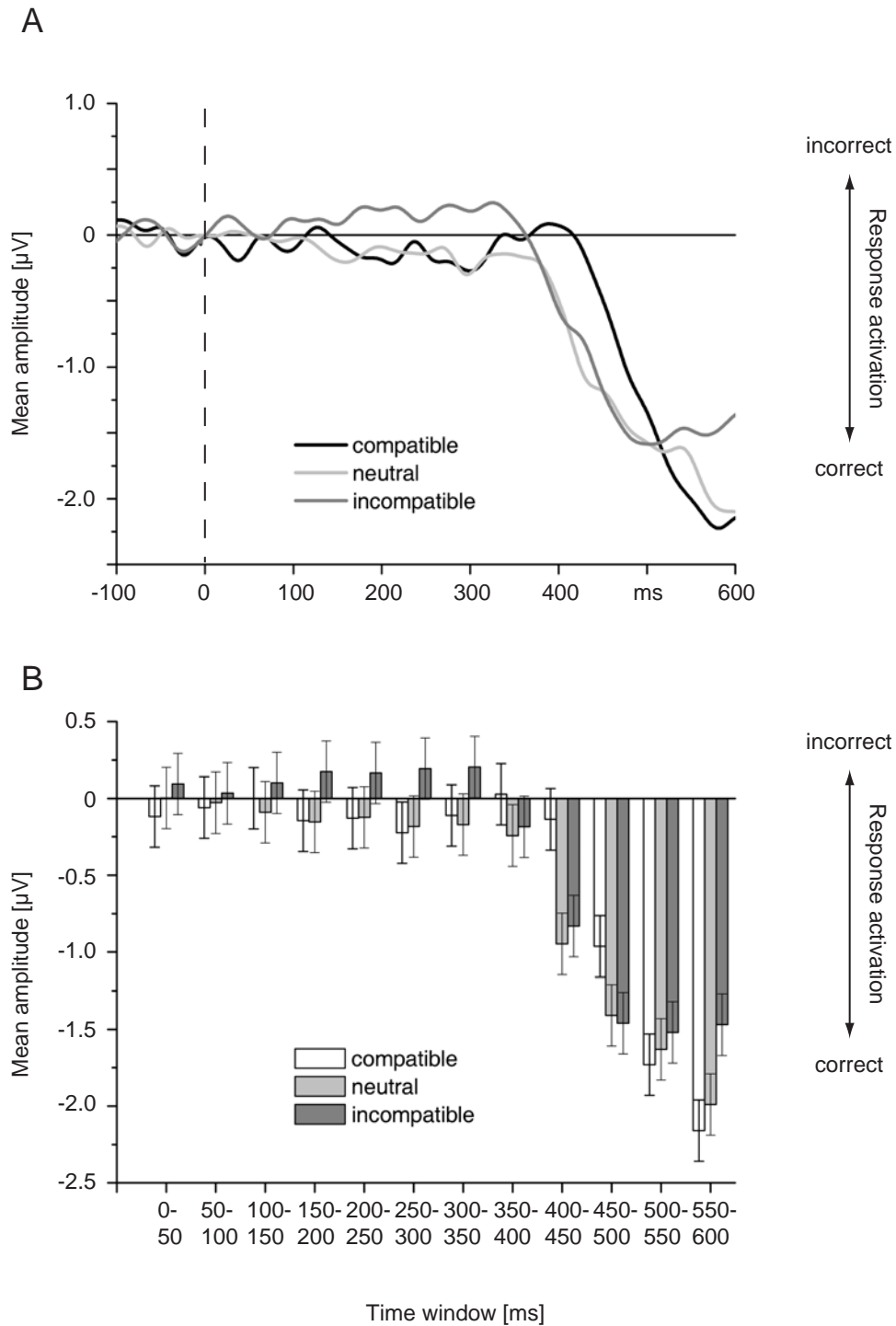


Figure 3.20: (A) Response-related LRP waveform for compatible (black), neutral (light gray), and incompatible (dark gray) trials and (B) mean amplitudes for the different time windows for compatible (white), neutral (light gray), and incompatible (dark gray) trials from the forced-choice priming task of Experiment 3. Negative LRP deflections (amplitude values) indicate correct (response-consistent) response activation and positive LRP deflections (amplitude values) incorrect (response-inconsistent) response activation. Error bars show 95 % within-subjects confidence intervals (Loftus & Masson, 1994).

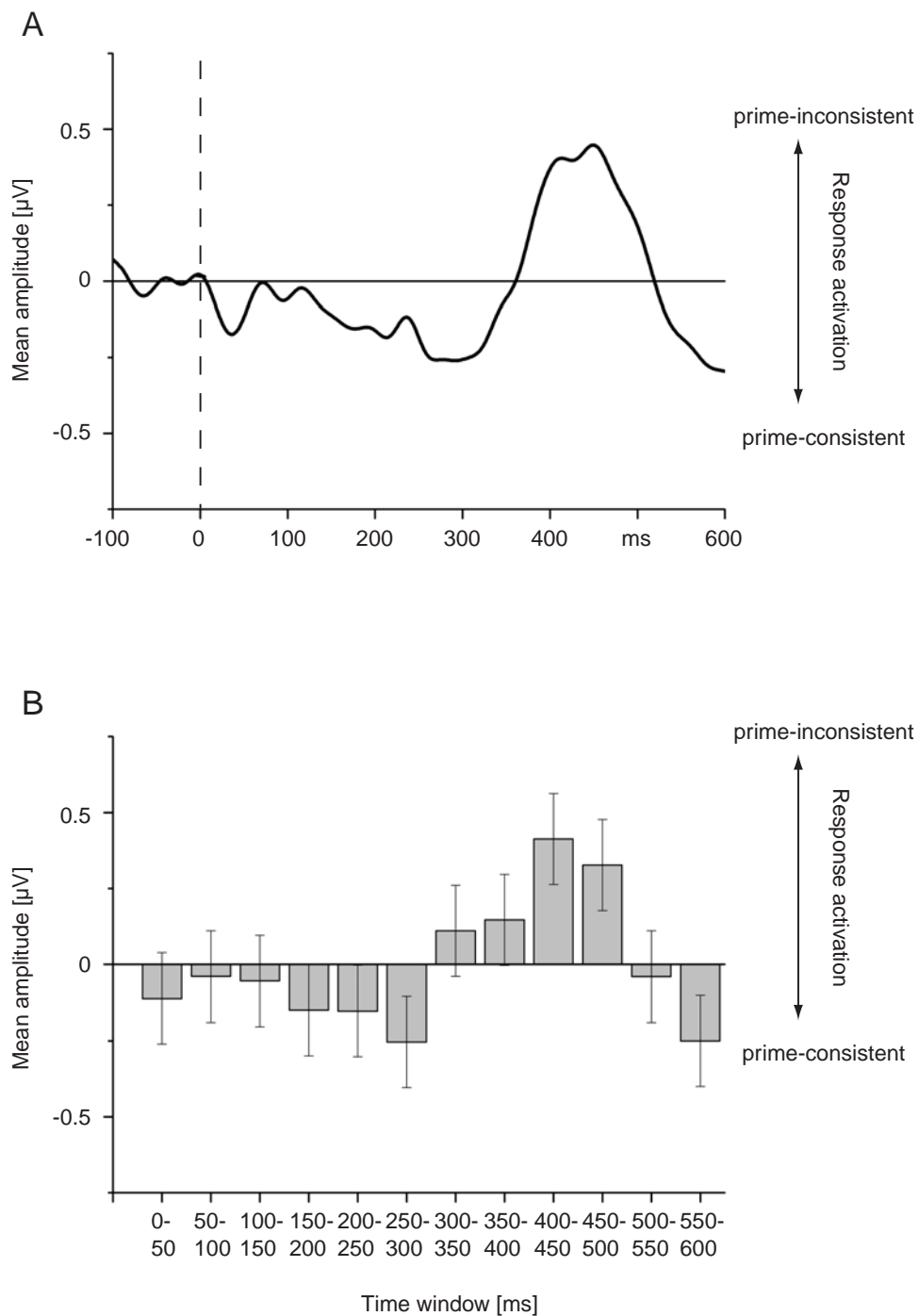


Figure 3.21: (A) Prime-related LRP waveform for averaged compatible and incompatible trials and (B) mean amplitudes for different time windows of the forced-choice priming task of Experiment 3. Negative LRP deflections (amplitude values) indicate prime-consistent response activation and positive LRP deflections (amplitude values) prime-inconsistent response activation. Error bars show 95 % within-subjects confidence intervals (Loftus & Masson, 1994).

3.3.4 Discussion

Experiment 3 aimed to investigate the time course of the response activation induced by masked action-effect primes found in Experiment 2. To this end, the time between the offset of the effect-prime and the onset of the Go-signal was increased to 100 ms. The results obtained for the Go-trials of the free-choice test-phase indicated that prime-related response activation started at about 150 ms after prime-onset. As in Experiment 2, this early (prime-induced) response activation was reliable only for acquisition-consistent key-choice trials. Thus, replicating the results of Experiment 2, the subliminally presented effect-primes re-activated their associated responses at least to a certain degree. This activation was stronger on trials on which the acquisition-consistent response was in fact executed. It is possible that the strength of the prime-induced response activation varied between individual trials and that, as suggested in the discussion of Experiment 2, on trials on which the prime-induced response activation was strong the likelihood increased that the already primed (acquisition-consistent) response was chosen (relative to trials on which prime-related response activation was weaker). Why should response priming differ in its magnitude on different trials? One explanation is that participants already decided *before* the effect-prime appeared which key they wanted to press in the case of a Go-signal. This premature decision might already have led to a partial activation of the "chosen" response. If now a prime appeared which had been associated with this "chosen" response the already existing partial response activation increased and an execution of this response after the Go-signal became more likely. In contrast to Experiment 2, the early prime-induced motor activity vanished after approximately 100 ms and stayed at baseline until final response-related motor activation started after the onset of the Go-signal (approximately 300 ms post-prime for acquisition-consistent and 350 ms post-prime for acquisition-inconsistent trials). One plausible explanation of why the early prime-induced motor activity returned to baseline is that the longer duration of the mask led to an automatic inhibition of the initially activated response (Eimer & Schlaghecken, 1998; Klapp & Hinkley, 2002). This would also additionally explain why, in contrast to Experiment 1, no prime-induced response bias was obtained in Experiment 3 and acquisition-consistent and acquisition-inconsistent key-choices were made equally often.

One open question is why no reliable prime-related response activation was obtained on the NoGo-trials. One explanation for this finding is that the effect-primers were not strong enough to induce reliable response activation on these trials. Although it has been shown in numerous ERP experiments that supraliminally presented stimuli which were explicitly mapped to specific responses in the instruction can trigger a partial activation of these responses even if no response execution is required after their presentation (e.g., Miller & Hackley, 1992), few studies have been conducted to investigate the influence of *subliminally* presented prime stimuli under conditions in which no overt response has to be executed. To further explore this issue, in Experiment 4 prime-related response activation on NoGo-trials was investigated in a forced-choice reaction task.

3.4 Experiment 4: Go/NoGo-priming control experiment

3.4.1 Introduction

In Experiment 2 and 3 a Go/NoGo paradigm was used in the free-choice test-phase. The analysis of the the LRP obtained from the Go-trials revealed reliable acquisition-consistent prime-related motor activation starting at about 200 ms after prime-onset. This result could not be replicated for the NoGo-trials, although one could have expected this result (Miller & Hackley, 1992).

In Experiment 2 and 3 the primes were effect-stimuli that had been associated with specific motor responses in a prior learning phase. Experiment 4 was conducted to investigate the time course of response activation in a combined forced-choice reaction and NoGo task. The main question was whether subliminally presented primes do activate associated responses on NoGo-trials when the primes are not action-effects, but stimuli which are mapped to particular actions by an explicit stimulus-response mapping specified in the instruction. Experiment 4 consisted of a forced-choice priming task with again response-compatible and -incompatible trials and an equal number of NoGo-trials. Thereafter a prime discrimination task was applied.

It was predicted that RTs on Go-trials should be longer in this combined Go/NoGo-task relative to the Go-trials in the pure forced-choice priming tasks of the previous three experiments (Eimer & Schlaghecken, 2001). Using a mixed forced-choice Go/NoGo design,

Eimer and Schlaghecken (2001) found that RTs in the Go-trials increased as a function of the number of NoGo-trials but that priming effects were unaffected by their number. One further prediction for Experiment 4 is reliable prime-induced motor activity in the LRP as early as 200 ms post-prime on Go- as well as on NoGo-trials.

3.4.2 Method

Participants

Seventeen students from the Dresden University of Technology (age 18-30, mean age 23.2; 13 female) participated in Experiment 4. All of them had normal or corrected to normal vision and reported no history of neurological or psychiatric disorders. They either received course credit or were paid Euro 5 per hour for their participation.

Stimuli, procedure, and design

Forced-choice priming task

The prime and target stimuli were identical to those used in Experiment 3 but a different mask was used which consisted of randomly arranged small dots (i.e., random-noise mask). The mask extended 1.81° visual angle. Each trial started with the presentation of a prime stimulus (square or diamond) for 16 ms. Following a blank interval of 32 ms the mask appeared for 16 ms. Immediately after the offset of the mask the target (square or diamond) appeared on 2/3 of all trials for 300 ms. Half of the participants were asked to press the left response key whenever a square appeared and the right response key if a diamond was the target (vice versa for the other half of the participants). On 1/3 of the trials the NoGo-signal (#) appeared, which indicated that no response had to be made (NoGo-trials). There were 648 trials overall (216 compatible, 216 incompatible, 216 NoGo). The task was divided into 12 experimental blocks (54 trials each). Before the main experiment participants were administered a practice block of 20 trials. The independent variable was trial type (compatible, incompatible, NoGo) and the dependent variables were RT [ms], error rate [%], and the LRP [μ V].

Prime discrimination task

The stimuli (i.e., the primes, the mask, and the Go-signal) were identical to the ones used in the forced-choice priming task. During the prime discrimination task a prime (one of the two primes from the forced-choice priming task) was presented for 16 ms. Immediately after the offset of the prime a blank screen appeared for 32 ms and was followed by the mask which stayed on the screen for 16 ms. After the mask a Go-signal appeared and participants were asked to indicate (or guess) which prime they had seen prior the the mask (diamond or square). There were 100 trials overall (each prime was presented 50 times). The task was divided into 2 experimental blocks (50 trials each). Before the first experimental block participants were administered a practice block of 10 trials.

EEG data acquisition

The EEG was recorded during the force-choice priming task. Twenty-three electrodes were used (F3, Fz, F4, FC3, FC1, FC2, FC4, T7, T8, P7, P3, Pz, P4, P8, O1, O2, F7, F8; for the reference and EOG see Experiment 2). The data was sampled at a rate of 1000 Hz with a low cut-off of 10s (0.0016 Hz) and a high cut-off of 250 Hz. Offline a notch-filter (50 Hz) and a high cut-off filter of 80 Hz were applied to the data and the sampling rate was changed to 250 Hz. All impedances were kept below 5 k Ω throughout the experiment. The segmentation, baseline correction, artifact rejection, and LRP calculation methods were equivalent to those used in Experiments 2 and 3.

The Experiment started with the forced-choice priming task followed by the prime discrimination task. It took about 2 hours to complete the entire experiment.

3.4.3 Results**Behavioral performance***Forced-choice priming task*

The mean correct RTs for the compatible and incompatible trials are shown in Figure 3.22. RT outliers (RTs below 200 ms and above 2000 ms and RTs on which the score deviated from the mean score for that experimental condition with an absolute value for $z > 2.5$; 1.6% of all trials) and trials on which a response error was made (2.2% of all trials) were

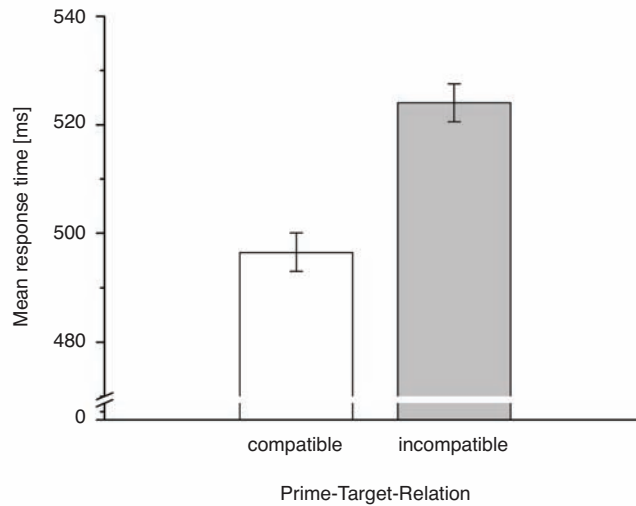


Figure 3.22: Mean correct response times (RTs) for compatible (white) and incompatible (gray) trials of the priming task of Experiment 4. Error bars show 95 % within-subjects confidence intervals (Loftus & Masson, 1994).

excluded before further analysis. The mean RT on compatible trials (496 ms [SE mean 12.8] was significantly faster than on incompatible trials (524 ms [SE mean 11.7] ($F(1,16) = 30.9$, $MS_e = 208.08$, $p < .001$). Correspondingly, the error rate was significantly higher for incompatible than for compatible trials (1.6% [SE mean .43] and 2.7% [SE mean .53] for compatible and incompatible trials, respectively; $F(1,16) = 6.1$, $MS_e = 1.578$, $p < .03$). The false alarm rate in the NoGo-trials was 2.9%.

Prime discrimination task

Participants correctly identified the primes on 50.7% [SE mean .9] of all trials, which was not significantly different from the chance level ($t(16) = .491$, $p > .50$).

Electrophysiology

Compatible vs. incompatible vs. NoGo-trials: To investigate prime-induced response activation for the three conditions I calculated the response-related LRP separately for the compatible and incompatible trials (see Figure 2.5, page 29) and the prime-related LRP (see Figure 3.8, page 52) for the NoGo trials (Figure 3.23 A). As in the other experiments,

the waveforms were divided into 50 ms time windows from prime-onset to 600 ms after prime-onset. The mean amplitude values of the time windows are shown in Figure 3.23 B.

Separate ANOVAS for the mean amplitude values of the response-related LRP of the Go-trials (time window [1-12] by compatibility [compatible, incompatible]) and the prime-related LRP of the NoGo-trials (time window [1-12]) were conducted. The ANOVA for the Go-trials revealed a significant main effect for time window ($F(11,176) = 50.83$, $MSe = .585$, $p < .001$). This was due to overall more negative (correct) response activation on later time windows. The main effect of compatibility failed significance ($p > .10$). The differences between the LRP waveforms from the compatible and incompatible trials were substantiated by a significant time window-by-compatibility interaction ($F(11,176) = 5.00$, $MSe = .245$, $p < .001$). The compatible and incompatible waveforms were significantly different from each other starting 250-350 ms post-prime ($ts(16) > 2.5$, $p < .03$). The compatible LRP waveform indicated reliable prime-induced "correct" response activation (significantly more negative than baseline) starting at about 250 ms ($ts(16) > 2.8$, $p < .02$). The incompatible LRP waveform did not differ from the baseline until 350 ms post-prime when it started to become significantly more negative than zero indicating target-related correct response activation ($ts(16) > 3.3$, $ps < .005$). The main effect for time window for the NoGo-trials did not reach significance ($p > .30$). Although on a descriptive level, the NoGo LRP was more negative than the baseline in the time windows starting 250 ms post-prime, it never differed significantly from zero indicating that the primes did not elicit a reliable response activation on the NoGo-trials. The compatible and the NoGo waveform differed significantly from each other starting from about 350 ms post-prime due to final response activation on compatible trials ($ts(16) > 3.5$, $ps < .003$). The incompatible and the NoGo LRP differed reliably starting from 400 ms onwards when the final response activation on the incompatible trials started ($ts(16) > 3.2$, $ps < .005$).

Overall prime activity on the Go-trials: To examine the "net" magnitude of response activation elicited by the primes on the Go-trials the prime-related LRP waveform of the averaged compatible and incompatible trials was computed (Figure 3.24 A). As in the previous experiments, these prime-related waveforms do not reflect response activation caused by the actually executed responses, but rather indicate response activation induced by the

subliminal primes, irrespective of which response was actually performed (see Figure 3.8, page 52). The resulting waveform was divided into 50 ms time windows (0-600 ms post-prime) and the mean amplitudes in these time windows were computed (Figure 3.24 B). An ANOVA of these mean amplitudes with the factor time window (1-12) revealed a significant main effect ($F(11,176) = 4.96$, $MSe = .129$, $p < .001$). Two-sided t-tests revealed that the LRP was significantly more negative from zero 250-400 ms post-prime indicating prime-consistent response activation during these time windows ($ts(16) > 2.5$, $p < .03$).

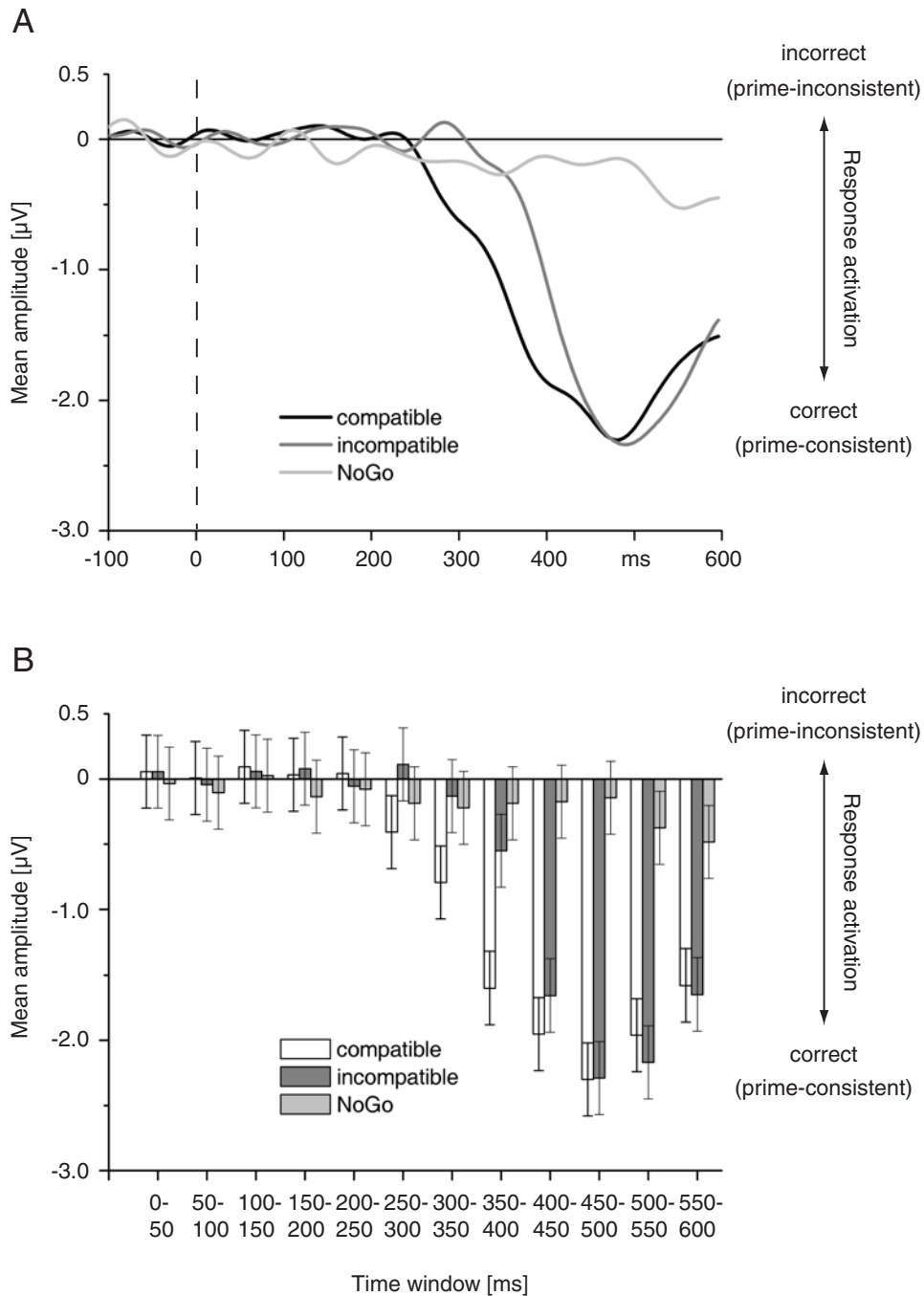


Figure 3.23: (A) Response-related LRPs for the compatible- (black) and incompatible-trials (dark-gray), and the prime-related LRP for the NoGo-trials (light-gray) of the forced-choice priming task of Experiment 4. Negative LRP deflections (amplitude values) indicate correct response activation and positive LRP deflections indicate incorrect response activation for the compatible and incompatible waveform and prime-inconsistent response activation for the NoGo waveform. Error bars show 95 % within-subjects confidence intervals (Loftus & Masson, 1994). (B) Mean amplitudes for the different time windows for the compatible- (white), incompatible (dark-gray), and NoGo-trials (light-gray) of the forced-choice priming task of Experiment 4. Negative LRP deflections (amplitude values) indicate correct response activation and positive LRP deflections indicate incorrect response activation for the compatible and incompatible waveform and prime-inconsistent response activation for the NoGo waveform. Error bars show 95 % within-subjects confidence intervals (Loftus & Masson, 1994).

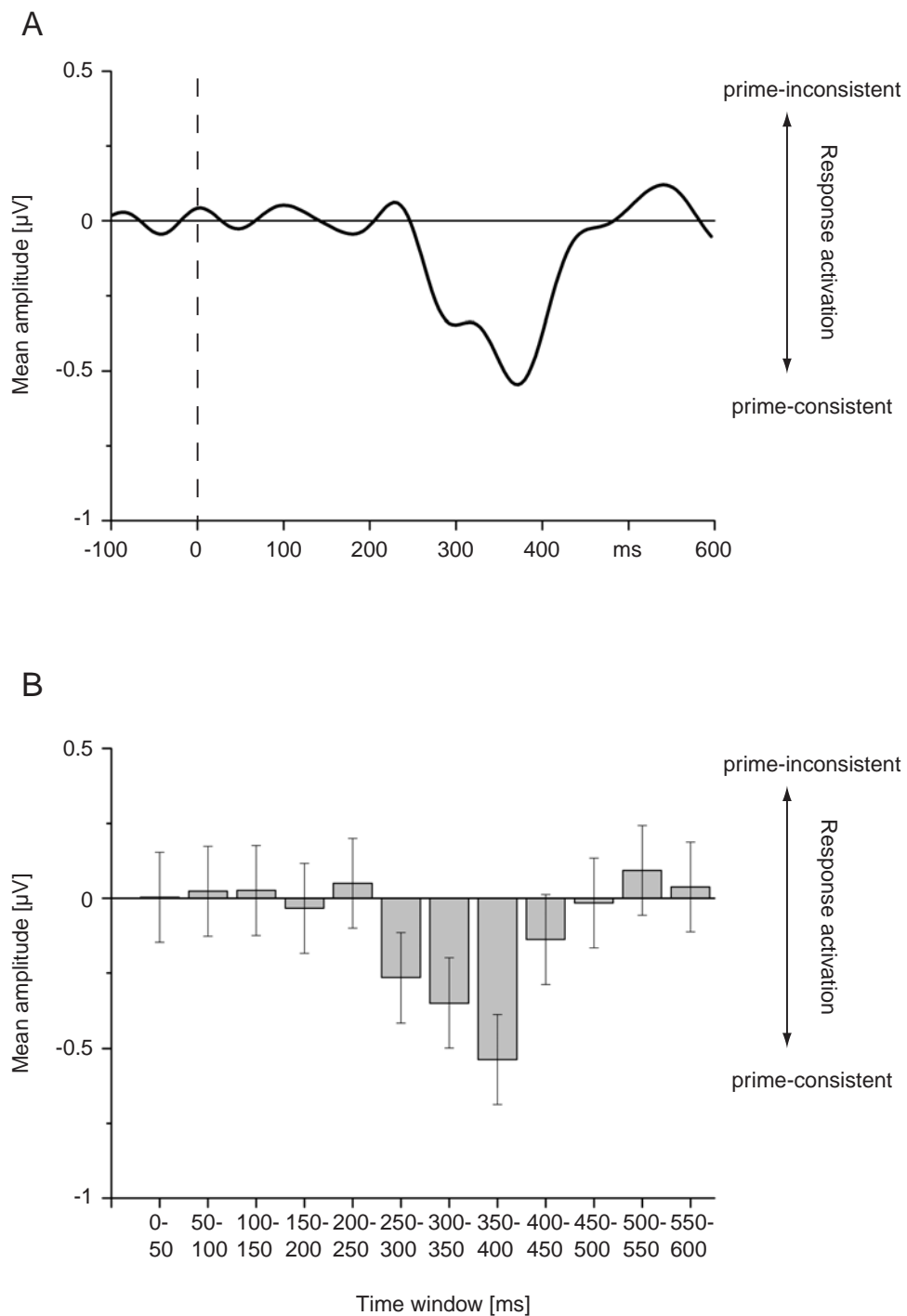


Figure 3.24: (A) Prime-related LRP waveform for averaged compatible and incompatible (Go-) trials and (B) mean amplitudes for different time windows of forced-choice priming task of Experiment 4. Negative LRP deflections (amplitude values) indicate prime-consistent response activation and positive LRP deflections (amplitude values) prime-inconsistent response activation. Error bars show 95 % within-subjects confidence intervals (Loftus & Masson, 1994).

3.4.4 Discussion

Experiment 4 was conducted to investigate partial response activation by subliminal primes in Go- and NoGo-trials in a forced-choice reaction task. The behavioral results of the Go-trials revealed a positive compatibility effect (PCE) of 28 ms, which was of the same magnitude as the PCE effect obtained in Experiments 1 and 2 or the NCE obtained in Experiment 3. This shows that reducing general response readiness by inserting a larger number of NoGo-trials did not affect the overall impact of the primes. Rather the subliminal primes still activated the motor response to which they were mapped in the instruction. This was also evident in the LRP data. The analysis of the prime-related LRP showed that partial prime-related response activation was visible starting at about 250 ms post-prime and lasting for approximately 150 ms. Separate analyses for response activation for response-compatible and -incompatible trials showed that this early prime-induced response activation was reliable for the compatible trials only. In contrast, there was again no reliable early prime-related response activation on the NoGo-trials. Why is prime-related response activation evident for Go- but not for NoGo-trials? One possible explanation is that the appearance of the NoGo-signal led to a fast inhibition of motor activity induced by the primes resulting in smaller LRP amplitudes for NoGo-trials. It is a question for further research to investigate under which conditions automatic response activation by subliminal primes may also be observed on NoGo-trials.

3.5 Experiment 5: Emotional action-effects - a pilot study

3.5.1 Introduction

In Experiments 1-3 action-effects with visual, directly perceivable features have been used. However, action-effects in everyday life are often not only characterized by their sensory features, but also have subjective, e.g., emotional features and differ with respect to the motivational significance they have for an agent. It seems likely that codes of emotional features are also integrated into action representations and play an important role in action control (Beckers et al., 2002; Hommel, in press). In research on decision making this idea is of course by no means new. For instance, Damasio (1994) assumes that

performing actions produces positive or negative outcomes, which trigger specific somatic states. These somatic states then become associated with representations of the action and are assumed to bias subsequent decision-making processes and choices between actions. This process is similar to the acquisition of action-effect associations. If humans have to decide how to act in a certain situation they can anticipate which somatic states each action would lead to and base their decision on these "somatic markers". Damasio (1994) assumes that a distributed neural network is responsible for the acquisition and use of such links between actions and somatic markers. Of central importance is the orbitofrontal cortex, which is assumed to be critically involved in the association of anticipated action-effects and somatic markers (Damasio, Tranel, & Damasio, 1991).

There is initial evidence that the emotional valence of action-effects does in fact influence the selection of future actions. A study by Beckers et al. (2002) indicates that affective action-effect codes are also integrated in action representations along with other features. They used an instrumental learning paradigm with an acquisition-phase and a test-phase. During the acquisition-phase participants had to move a response key up- or downwards in reaction to a Go-signal. One of the two actions was consistently followed by an aversive electrocutaneous stimulus (negative action-effect). The other action was never followed by this aversive stimulus ("positive" action-effect). In the test-phase words with a negative or positive valence were presented and the task for the participants was to indicate whether the word they had just seen was a noun or an adjective (again by moving a response key up or down). After each response the same effect which had been produced by this effect during the acquisition-phase was administered. The results showed that responses that were consistently followed by a positive effect were emitted faster in response to positive targets and responses associated with negative effects were emitted faster in response to negative targets. While this result indicates that the congruence between the emotional valences of imperative stimuli and the emotional valences of action-effects influences response selection, to date it has not been shown whether the emotional valence of anticipated action-effects can influence free-choice actions. If the emotional valence of an action-effect becomes integrated into the action representations like other sensory features, it seems likely that perceiving or anticipating action-effects that have been associated with a positive or negative valence exert a differential influence on free-choices between actions.

Such a finding would be theoretically important because it would show that response priming by action-effects is not a completely automatic process, but rather modulated by the emotional significance of the action-effects. To investigate whether the anticipation of action-effects which have been associated with different valences influences the response choice in a free-choice task Experiment 5 was conducted. Experiment 5 consisted of an acquisition- and a test-phase. Unlike in the previous experiment, the action-effect primes of the test-phase of Experiment 5 were presented above the threshold of awareness (i.e., supraliminal). Thus no additional control tasks investigating the visibility of the effect-primes were necessary.

3.5.2 Method

Participants

Twenty-one volunteers (students from the Dresden University of Technology; age 18-29, mean age 23.5; 16 female, all right handed) participated in Experiment 5. All of them had normal or corrected to normal vision and reported no history of neurological or psychiatric disorders. They either received course credit or Euro 5 per hour for their participation.

Stimuli, procedure, and design

Acquisition-phase

The stimuli used in the acquisition-phase are shown in Figure 3.25. The cross used as a Go-signal extended 1.1° of visual angle. 30 pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1999) (15 with a positive and 15 with a negative emotional valence) served as action-effects. The positive and negative pictures only differed with respect to their valences (7.5 for positive and 2.63 for the negative pictures). The arousal was held constant (mean arousal value of the positive pictures was 4.8 and for the negative pictures 5.06) (see appendix A and B). The pictures were accompanied by one of two action-effect-tones (either 500 or 800 Hz; 200 ms duration).

Each trial of the acquisition-phase started with the presentation of a cross at the center of the screen. Immediately after the appearance of the cross the participants had to choose to press one of the two possible response keys. 50 ms after the key-press a picture

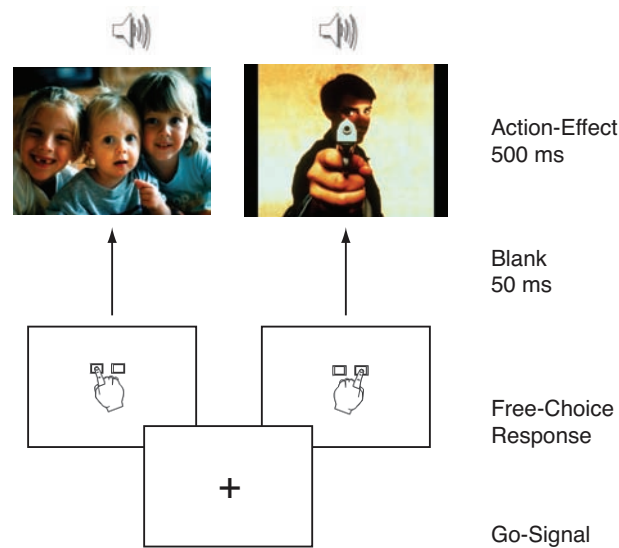


Figure 3.25: The sequence of events on a trial of the acquisition-phase of Experiment 5. After a Go-signal participants pressed one of two possible response keys. Shortly after the free-choice key-press an affective pictures accompanied by a tone appeared as action-effect.

accompanied by a tone appeared for 500 ms, which were both contingent on the given response. For each subject, the mapping of responses to pictures and tones was constant during the experiment (e.g., a right key-press was always followed by a positive picture and a 500 Hz tone). The mapping of responses to tones and pictures was counterbalanced across subjects. After an ITI of 1000 ms a new trial started. The acquisition-phase consisted of 200 trials and 10 additional practice trials (with neutral pictures and a different tone as action-effects) before the main block.

Free-choice test-phase

The effect-tones used in the acquisition-phase served as imperative stimuli in the test-phase. Each trial started with the presentation of a cross accompanied by one of the two tones from the acquisition-phase. After the tone subjects were asked to freely choose to press one of the two keys already known from the acquisition-phase. They were instructed to choose the key as spontaneously as possible and not to think about which key to press. After an inter-trial-interval (ITI) of 1000 ms a new trial started. The test-phase consisted of 100 trials divided into 2 blocks (each tone was presented randomly 50 times). Before

the main block 10 practice trials were administered. The independent variable was the emotional valence of the effect-tone (positive, negative). The dependent variable was the frequency of key-choices (acquisition-consistent vs. acquisition-inconsistent).

3.5.3 Results

Acquisition-phase

Both action-effects (i.e., high vs. low tones and positive vs. negative pictures) were produced equally often by the participant ($t(20) = -.43, p > .60$).

Free-choice test-phase

An ANOVA with the factors emotional valence (negative, positive) and consistency (acquisition-consistent vs. acquisition-inconsistent choices) revealed a significant main effect of consistency due to overall significantly more acquisition-consistent than inconsistent key-choices (59% [SE mean 3.4] vs. 41% [SE mean 3.4]; $F(1,20) = 6.67, MS_e = 239.67, p < .02$) (see Figure 3.26). The main effect of emotional valence as well as the interaction of emotional valence-by-consistency did not reach significance ($p > .50$ and $p > .50$, respectively). However, separate analyses for the two affect conditions revealed that the effect of consistency was only reliable for tones that had been associated with a positive emotional valence (30.7% [SE mean 2.4] vs. 19.1% [SE mean 2.3] for acquisition-consistent and acquisition-inconsistent key choices, respectively; $t(20) = 2.4, p < .03$). The analogous difference was not reliable for the negatively associated effect-tones (27.9% [SE mean 2.5] vs. 22.2% [SE mean 2.5] for acquisition-consistent and -inconsistent choices, respectively; $t(20) = 1.13, p > .20$).

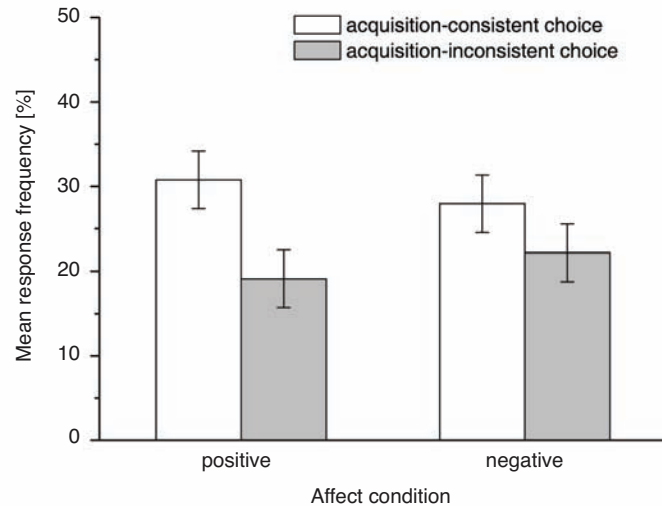


Figure 3.26: Mean response choice frequency in the free-choice test-phase of Experiment 5.

3.5.4 Discussion

Experiment 5 was conducted to investigate if free-choice actions are influenced by the emotional valence of the anticipated consequences of the action. The results of the acquisition-phase indicated that on average both action-effects were experienced equally often and should therefore have been associated with the actions to equal degrees. The free-choice test-phase revealed a response bias in the sense that participants more frequently chose the responses that had been associated with the effect-stimuli in the acquisition-phase, compared to acquisition-inconsistent responses. Planned comparison showed that this effect was reliable only for action-effects that had been associated with a positive emotional valence. If negatively valenced action-effects were presented as imperative stimuli in the free-choice test-phase, no reliable response bias was obtained. That the two conditions (positive vs. negative action-effect primes) produced different results indicates that the affective codes of the action-effects were automatically integrated into the action representation during the acquisition-phase. For the positively associated action-effects, the perception of one feature of the action representation (the effect-tone) obviously led to

the activation of the remaining parts of the representation, including affective codes and motor codes. This result is in line with the findings by Beckers et al. (2002) and the ideas of Damasio (1994) discussed above.

There are at least two possible explanations for the non-reliable response bias when negatively valenced action effects served as imperative stimuli in the test-phase. First, the strength of the association between the response codes and the effect codes during the acquisition-phase might have been weaker in the negative condition. This seems unlikely in the light of previous findings indicating that the binding of response codes and effects codes occurs automatically (Elsner & Hommel, 2001). A second explanation is that both negatively and positively valenced action-effects initially led to an activation of the associated responses, but that in the negative condition this activation was inhibited later on because the anticipated negative affect associated with the action-effect (i.e., the tone stimulus) was aversive and thus elicited a tendency to avoid the action producing this effect (Gray, 1990). By contrast, encountering a positively valenced action-effect should have facilitated the activation of the corresponding action by inducing an approach-oriented response.

The results of Experiment 5 are relevant for ideomotor theories of action control in general by showing that the emotional valence of action-effects becomes integrated into action representations as well. Importantly, response priming or selection by features of former action-effects seems to be modulated by emotional and motivational factors. Specifically, the results of Experiment 5 indicate that the degree to which an action-effect activates associated motor codes (or whether this activation leads to response execution) depends on the emotional valence of the action-effect.

Chapter 4

General discussion

4.1 Summary of the results

The general aim of this dissertation was to investigate the role of action-effects in action control. For this purpose five experiments using behavioral and electrophysiological measures (EEG) were conducted, supplemented by methodological control experiments.

Two main questions motivated this thesis. The first major question was whether the presentation of subliminal (i.e., not consciously perceivable) action-effects automatically activates motor responses, which formerly have been experienced to cause these effects. If so, can this (partial) response priming by action-effects bias free-choice actions? To address these points Experiments 1-3 were performed. Each experiment consisted of two experimental phases. The acquisition-phase was a learning phase in which simple key-press actions were followed by simple visual stimuli, that were contingent on the actions. Immediately after the acquisition-phase the test-phase followed, in which participants performed free-choice actions after the presentation of a Go-signal. In Experiments 2 and 3 a NoGo-signal indicating that a response had to be withheld could appear with the same likelihood as the Go-signal. Unknown to the participants, one of the former action-effects was presented subliminally prior to each Go- and NoGo-signal. Additionally, two control tasks and a questionnaire were administered to investigate whether the primes indeed remained unconscious and whether they were generally able to influence behavior. The fact that the action-effects presented during the acquisition-phases were neither task-relevant

nor had a specific meaning for the participants and could thus be ignored supports the assumption of an automatic integration of the motor codes of action and the sensory codes of their effects (Elsner & Hommel, 2001). Taken together, the results obtained in the test-phase provided strong evidence that even subliminally presented action-effects can automatically activate corresponding motor codes. Under certain circumstances the partial response activation was found to bias free-choice actions although participants experienced the actions as freely chosen. The response priming by action-effects became evident in the lateralized readiness potential (LRP), an electrophysiological indicator of response activation. At least three factors seemed to influence which responses were chosen and executed: The strength of the priming effect, the complexity of the task (i.e., pure Go-blocks or intermixed Go/NoGo-blocks), and the elapsed time between the prime stimulus and the Go-signal. Control tasks confirmed that the experimental setup was in principle suited to investigate unconscious response priming and supported the major findings of Experiments 1-3. In particular, forced-choice discrimination tasks showed that the primes were indeed not consciously perceived as indicated by the fact that participants were not able to identify the masked primes better than chance. Moreover, forced-choice priming tasks proved that the masked (effects)-primes used in the free-choice test-phase were indeed able to activate motor responses to which they had been explicitly mapped in the instruction.

A secondary question of this thesis concerned the role of emotional features of action-effects. In Experiment 5 I investigated whether the emotional valence of action-effects is automatically integrated into action representations (as has been shown for other sensory features of action-effects) and whether the prime-induced anticipation of action-effects with different emotional valences exert different influences on free-choice actions. To address this question, in Experiment 5 simple key-press actions were linked to action-effects with different emotional valences (positive vs. negative pictures accompanied by high or low tones) during the acquisition-phase. In the subsequent test-phase, the effect-tones that had been associated with negative or positive pictures were presented and followed by a Go-signal, after which participants had to freely choose to press one of the two response keys. Results indicated that the emotional valences of action-effects are automatically integrated into action representations and that the anticipation of the emotional valence

of an action-effect influences free-choice actions. Whereas the effect-tones induced a clear response bias (i.e., more acquisition-consistent than -inconsistent key-choices) when they had been associated with a positive emotional valence, this response bias was not reliable for action-effects associated with negative emotional features.

In summary, the present results provide further proof for ideomotor theories of action control (James, 1890; Elsner & Hommel, 2001). They showed that the presentation of action-effect features automatically activates associated response codes, even if the effect-representation remains below the threshold of conscious awareness. Moreover, the results showed that the response activation induced by subliminal effect-primers can bias free-choice actions. Whether or not prime-induced response activation becomes evident in the actual execution of the primed response depends, however, on a number of additional factors including task complexity, temporal factors, and the emotional valence of the anticipated action-effects. The next sections of this chapter will discuss the obtained results in more detail. The discussion will start with a closer look at the boundary conditions and the time course of response priming induced by subliminal action-effects.

4.2 Unconscious response priming by action-effects

4.2.1 Automatic response activation by effect representations

One of the main questions of this dissertation was whether or not action-effects, which have been associated with simple responses, are able to automatically activate their associated motor codes even if they are presented subliminally and processed unconsciously. Experiments 2 and 3 were conducted to directly answer this question by using the LRP as an indicator of response activation. The results of the test-phase of both experiments revealed acquisition-consistent prime-induced motor activation, that is, the subliminal effect-primers activated the responses that had been associated with them during the acquisition-phase. This was in particular true for the Go-trials, on which a free-choice response had to be executed. This finding suggests that the sensory features of former action-effects automatically activated responses with which they had been associated during the acquisition-phase. This response activation was evident in the LRP starting about 150-200 ms after the onset of the action-effect primers and is in accordance with ideomotor views of action

control, which assume that actions are automatically activated by anticipating their consequences (Elsner & Hommel, 2001; Harless, 1861; Hoffmann, 1993; James, 1890; Lotze, 1850; Prinz, 1997). The results are also in accordance with a brain imaging study by Elsner et al. (2002) which showed increased activity in the caudal supplementary motor area while participants merely perceived former action-effects. Importantly, the results of the present experiments indicate that action-effects do not have to be consciously perceived or anticipated to activate associated motor patterns. The fact that action-effect stimuli that were kept below the threshold of awareness nevertheless induced reliable response activation provides strong support for the assumption that response priming by action effects is indeed an automatic process. Since the effect-primers in the present experiments were subliminal, their influence on the response activation as indicated by the LRP cannot be attributed to conscious expectations or intentional strategies (which may have played a role in earlier studies using supraliminal effect-primers).

At first glance, the idea that unconscious effect representations automatically influence behavior by activating associated actions may seem counterintuitive. However, in everyday life such a mechanism appears adaptive because it supports the fast selection of appropriate actions depending on environmental conditions. We often act appropriate without conscious deliberation and may even find it difficult to say why we did what we did (Bargh, 2005). One example is shifting gears while driving a car. Once we have learned which actions are necessary to operate the gear shift we automatically shift to a higher gear if we feel that we drive faster or if we hear that the engine sounds too loud. In a highly experienced driver, the increased noise automatically activates a goal representation (to reduce the noise level of the engine) and this goal representation activates motor codes, which have been learned to produce the intended effect (i.e., gear shifting actions). The automatic activation of the gear shifting goal by specific stimulus conditions and the automatic activation of actions suited to attain this goal reduce the demands on processing resources and thus allow us to perform other actions at the same time (e.g., following a conversation while driving). If looking at the car driving example above, one precondition for automatic response priming by action-effects in most everyday life actions seems to be practice (Ziessler & Nattkemper, 2002). Before automatic response priming by effect anticipation can take place the effect that an action will produce has to be known. This

action - effect (R-E) learning process is likely to be mediated by awareness. However, after the association between an action and its effects has been formed the realization of the effect (i.e., the recruitment of appropriate actions to obtain this effect) does not necessarily have to be conscious.

Possible influences of response priming strength on response choices

In the experiments reported here, automatic response activation by action-effects seemed to be overall weaker or even absent on trials on which participants chose the acquisition-inconsistent key after the presentation of the primes (i.e., the response which was *not* associated with the effect-prime). One possible explanation for this finding is that the effect-primes did not induce equally strong motor activation on each trial. If the activation of effect feature codes by the primes remains below a certain threshold, this activation will not be strong enough to prime the associated responses (Hommel, 2003). As a consequence, participants' free choices between the alternative actions will not be biased by the effect-primes. Thus according to this interpretation, the likelihood of prime-consistent response-choices was greater on trials with a large prime-related LRP, indicating strong response priming by the action-effects. It should be noted that this interpretation is based on purely correlational evidence (i.e., smaller prime-induced response activation on trials on which participants chose the prime-inconsistent action), and further research would be required to provide evidence for a causal relationship between the strength of prime-induced response activation and the prime-induced biasing of free-choice actions.

Response activation on NoGo-trials

Whereas reliable evidence for response activation by subliminal effect-primes was obtained on the Go-trials of the free-choice test-phases, less clear results were observed on NoGo-trials. In contrast, several EEG studies have shown that partial response activation is visible even if a stimulus-triggered response has to be inhibited after the appearance of a NoGo-signal (Miller & Hackley, 1992; Osman et al., 1992). Furthermore, Schlaghecken and Eimer (2001) provided evidence that even a large number of NoGo-trials in a forced-choice reaction task do not reduce the effects of subliminal primes on behavioral performance. In the light of these findings, reliable prime-induced response activation was expected also on

the NoGo-trials in the experiments reported here. Consistent with this prediction, in the test-phase of Experiment 2 planned comparisons revealed a reliable response activation on NoGo-trial of similar magnitude than on Go-trials. However, this result could neither be replicated in the free-choice test-phase of Experiment 3 nor in the forced-choice task of Experiment 4. In Experiment 4, prime-induced response activation was overall weaker as indicated by smaller LRP amplitudes on the Go-trials relative to the LRPs in the forced-choice priming tasks of Experiments 2 and 3. Since this may also explain the non-reliable priming effect on the NoGo-trials, further research is clearly needed to elucidate this issue.

4.2.2 Unconscious effects representations can bias free-choice actions

The present LRP results consistently showed that unconsciously presented action-effects do indeed automatically induce a partial activation of associated motor patterns. However, the free-choice performance was found to vary across experiments. Consistent with earlier studies (Elsner & Hommel, 2001) more acquisition-consistent relative to -inconsistent responses were chosen in the free-choice test-phase of Experiment 1. Such a prime-induced response bias was predicted from the perspective of ideomotor theories of action control. If the perception of action-effect features automatically triggers associated motor patterns, this activation should also influence response choices. The relative small magnitude of the observed response bias (53% acquisition-consistent vs. 47% -inconsistent choices) is unsurprising given that participants' choices were also influenced by factors other than motor activation induced by action-effect features (for instance, some participants may have used idiosyncratic strategies to make their choices, which may have attenuated the subtle influence of the subliminal primes). Further, response activation and response execution (i.e., the implementation of the response) are believed to be independent processes (Elsner & Hommel, in press). Therefore, even if the effect-primers automatically activate their associated response codes this does not mean that this activation leads to an automatic execution of the primed response. An influence of this action-effect based priming-effect on action initiation and execution is however possible (Kunde et al., 2002; Kunde et al., 2004; Kunde, 2006), especially in cases where action-effect associations are very stable and not much top-down control is needed (e.g., in well-practiced musicians).

By contrast to Experiment 1, no response bias was obtained in Experiments 2 and 3

(i.e., an equal number of acquisition-consistent and -inconsistent responses were chosen). What could be reasons for this finding? One possible explanation for the missing response bias could be that response priming was overall weaker in Experiments 2 and 3 as compared to Experiment 1. Fewer primes than in Experiment 1 could have reached the necessary threshold to induce sufficient effect-feature activation, which would then also not lead to an activation of associated motor codes. However, this explanation seems unlikely as the action-effects and masks used in the Experiments 1 and 2 were identical in their physical appearance (the effect-stimuli and mask used in Experiment 3 varied slightly in shape and color from those of Experiment 1 and 2). Another, more likely, explanation for the equal number of acquisition-consistent and -inconsistent response-choices in Experiments 2 and 3 is, that the prime-induced response bias depends on the complexity of the task, i.e., whether additional processes intervened between the onset of the effect-prime and the response-choice. In the test-phase of Experiment 1 only Go-trials were used, thus responses could be executed immediately after the appearance of the Go-signal without any need to further process the Go-signal. By contrast, in Experiments 2 and 3 responses could not be executed that fast because a NoGo-signal could appear as well and thus a more detailed elaboration of the signal-stimulus was necessary. This additional discrimination process was time consuming, as indicated by longer RTs to the Go-signal in Experiments 2 and 3 as compared to Experiment 1. It is possible that this further attentional processing attenuated or even eliminated the already small response biases induced by the subliminal effect-primers. Furthermore, and also due to the Go/NoGo-design, participants had to stay more focused on the task in Experiments 2 and 3 as compared to Experiment 1 as they had to elaborate the 'Go'-signal in more detail. The increased recruitment of top-down (intentional) control could have reduced the influence of automatic, bottom-up processes on subsequent behavior. The automatically induced motor activity by the effect-primers might thus not have been strong enough to bias response choices in Experiments 2 and 3. In Experiment 1 the task was simpler and required less top-down processing, as participants simply had to press a key as soon as the Go-signal appeared. This presumably led to a stronger prime-induced bottom-up response activation, resulting in a greater influence of the effect-primers at the response execution stage (cf. de Jong et al., 1999). Alternatively, the response bias in the free-choice test-phase could also depend on the time interval

between prime-onset and response execution. As noted above, the response bias was only found if responses could be executed immediately after the presentation of the effect-primers, i.e., at a point in time when prime-induced response activation was probably maximal. A simple postponement of response execution would probably lead to a decay (or inhibition) of prime-related motor activity and thus an attenuated or even eliminated response bias. This hypothesis will be discussed in more detail in the next section.

Although the question if subliminally presented action-effects can bias free-choice responses is interesting in itself the main question of this dissertation was if they are able to induce associated motor activity. That the latter was indeed the case has been clearly shown by the LRP data from the free-choice test-phases of Experiments 2 and 3.

4.2.3 The time course of the unconscious response priming effect

Once an association between motor codes and effect codes is established via learning, the effect codes can automatically "trigger" their corresponding motor codes. As noted above, such automatic and unconscious response-priming is helpful if the activated response is the one required in a given task or situation or if it is the one most likely leading to a desired result. However, inhibition of automatically activated response tendencies may also be necessary on some occasions, for instance when inappropriate response tendencies have been triggered or if a quick modification of an activated response is required. Numerous studies have shown that response inhibition plays an important role in action control, for instance, by using stop-signal or Go/NoGo tasks (e.g., De Jong, Coles, Logan, & Gratton, 1990; De Jong, Coles, & Logan, 1995; Eimer, 1993; Kok 1986; Logan & Cowan, 1984). In these experiments response inhibition is initiated once a stimulus is recognized which signals the observer to refrain from responding. This type of inhibition is voluntary (intentional) and optional and thought to be mediated by executive mechanisms in prefrontal cortex (Band & Boxtel, 1999).

For a long time it has been argued that inhibitory control is restricted to consciously perceivable stimulation (e.g., Allport, Tipper, & Chmiel, 1985; McCormick, 1997; Marcel, 1980; Merikle, Joordens, & Stolz, 1995). However, recently it has been shown that inhibition may also result from unconscious processes. Eimer and Schlaghecken (1998) provided evidence that motor activity triggered by unconscious stimuli is automatically inhibited

after some time (at approximately 300 ms after the onset of the primes; see 2.3.2, 20 for details on the activation-followed-by-inhibition hypothesis). This activation-followed-by-inhibition process is not evident for consciously perceived primes, suggesting that different mechanisms are recruited by the cognitive system depending on the conscious availability of information. Whereas intentional regulatory mechanisms may be employed to prevent the execution of "unwanted" response tendencies under conscious conditions (Houghton & Tipper, 1994), an automatic inhibitory process is necessary to regulate the suppression of motor activity triggered by unconscious stimuli of which we are not aware. Could such exogenous response inhibition also affect the time course of unconscious response-priming by action-effects? In Experiments 1, 2 and 4 such an inhibitory mechanism seems unlikely because the time between the onset of the prime and the onset of the Go- or NoGo-signal was too short for inhibition to be initiated. The LRP data from the free-choice test-phases of these experiments support this assumption because no inhibitory processes were evident in the LRPs from the acquisition-consistent and -inconsistent trials. Also, the behavioral results of the forced-choice priming tasks of Experiments 1, 2 and 4 revealed positive compatibility effects (i.e., shorter RTs for compatible as compared to incompatible trials) suggesting that no inhibition took place (this was also confirmed by no reliable inhibitory activity in the LRP data from these tasks).

By contrast, the results obtained during the free-choice test-phase of Experiment 3 support the speculation that motor responses activated by the effect-primes were (at least to some extent) subsequently inhibited. In Experiment 3, the duration of the mask after the prime was longer as in Experiments 1, 2 and 4 (100 ms vs. 16 ms), which led to an increased SOA between prime and Go/NoGo-signal. This additional time was presumably sufficient for the mobilisation of automatic inhibitory processes (Eimer & Schlaghecken, 1998; Klapp & Hinkley, 2002). Consistent with this assumption, the LRP obtained from the Go-trials of the free-choice test-phase of Experiment 3 showed that the unconscious effect-primes activated their associated responses. This initial response activation returned to the baseline after approximately 100 ms as would be expected for automatic inhibitory processes (Eimer & Schlaghecken, 1998). Similar results were obtained with the forced-choice priming task of Experiment 3. First, the behavioral data revealed a clear negative compatibility effect (NCE, i.e., shorter RTs for *incompatible*

trials as compared to compatible and neutral trials) which is an indicator for subsequent automatic response inhibition. Second, the LRPs from the compatible and incompatible trials of this task exhibited clear prime-related response activation about 150-200 ms after prime-onset, which was followed by an response inhibition phase ca. 100 ms later. The LRP from the Go-trials of the free-choice test-phase as well as from the compatible and incompatible trials of the forced-choice priming task of Experiment 3 did not show a *strong* inhibition-related activation of the *opposite* response as could be expected from data obtained by Eimer and Schlaghecken (1998). The elicited response activity in Experiment 3 merely returned to baseline level. However, the strength of the inhibition effect strongly depends on the stimuli used as primes, masks, and targets as well as on the prime-target SOA and therefore varies between experiments (Eimer & Schlaghecken, 2003).

Taken together automatic inhibition of motor activity initially elicited by effect-primes may explain the LRP results obtained in the free-choice test-phase of Experiment 3. Nevertheless, two alternative explanations are possible. First, the motor activity induced by the effect-primes could simply have decayed. This is unlikely because the time between the primes and the Go-signal (100 ms) seems too short for a passive decay to occur (prime - Go-signal SOA = 164 ms). Second, the mask stimulus used in the free-choice test-phase could have induced response activation opposite from that induced by the prime (Enns & Llerras, 2005; see 2.3.2, 20 for details on the object-substitution-hypothesis in masked priming). This explanation also seems unlikely since there was no strong opposite response activation visible in the LRP obtained during the test-phase of Experiment 3, which should be the case if the mask had activated the opposite response.

4.2.4 Automatic response activation and the free-will debate

The results of this dissertation provide further evidence that actions are automatically activated by perceiving or anticipating their consequences, even if representations of such consequences remain below the threshold of conscious awareness. The term "automatic" appears to imply that we cannot influence whether or not actions are initiated by our brain if certain trigger conditions are encountered. Does this mean that we cannot control our behavior? Are we completely determined by our learning history, genes and environment? These kinds of questions are of course not new and it is beyond the scope of this dissertation

to discuss the issue of free will (see Kane, 2002; Walter, 1999; Dennett, 2003; Pauen, 2004; Goschke & Walter, 2005). Nevertheless the results presented in this thesis are potentially of interest in the context of the free-will debate.

One of the first scientists who tried to make empirical contributions to this topic was the neurophysiologist Benjamin Libet (e.g., Libet et al. 1983). The results of Libet's experiments seemed to indicate that the initiation of our voluntary actions is indeed based on unconscious brain processes. In his experiment, subjects watched a rotating clock hand in form of a moving light dot which took 2.56 seconds for one rotation. The instruction for the subjects was to flex spontaneously the wrist of the right hand within a certain time window. After each movement, they were asked to report either the time at which they first 'felt the urge' (the intention) to make this freely willed movement (W judgement) or the time when they became aware of the actual movement (M judgement). To obtain a measure of movement-related activity in the brain the EEG was recorded and the readiness potential (RP; "Bereitschaftspotential") was computed as an indicator of response activity (see 2.3.3, page 26 for details on the RP). The most important and much discussed result was that the RP started about 250 ms before the reported 'urge to move', that is, at a point in time where participants had not yet formed the conscious intention to move. The authors concluded that the cerebral initiation of a spontaneous voluntary act begins unconsciously. This suggests that our brain initiates actions before we know that we want to move. Numerous methodological criticisms and philosophical questions concerning this result have been raised over the years (e.g., Goschke & Walter, 2006; Trevena & Miller, 2002; Gomes, 2002). However, the basic finding has been replicated in other studies and with different methods (Keller & Heckhausen, 1990; Haggard & Eimer, 1999). Importantly, other interpretations of this result have been proposed. For instance, Keller and Heckhausen (1990) suggested that the movements in Libet's experiments were not - as assumed by Libet - purely self-paced, but instead reactions to internal stimuli. As the instruction to monitor the 'urge to move' or to register the moment at which one first has the intention to move is very vague, according to Heckhausen and Keller participants tried to identify some internal signal or indicator of that 'urge'. The perceived urge to move can then be interpreted as an internal stimulus, which triggered the activation of a motor pattern. To obtain evidence for their hypothesis, Heckhausen and Keller

conducted an experiment similar to the one by Libet et al. (1983). The results showed that during the entire experiment occasionally motor activity was evident (as indicated by the electromyogram (EMG) and RP) which participants were not aware of. Keller and Heckhausen (1990) proposed that participants constantly search for some internal event, which could be the 'urge to move'. What happens occasionally is that unconscious motor activity, which would otherwise not become conscious, reaches awareness and is interpreted as the 'urge to move'. If this motor activity signals the 'urge', it is no longer surprising that the RP starts before the intention to move becomes conscious.

Can the experience of an intention to move, that is experienced as a free "act of the will", also be induced by external (but unconscious) stimuli? This question could potentially be answered by an extension of the experimental paradigm used in this dissertation. For instance, subliminal effect-primers could be presented at random points in time during a Libet-like experimental setting. A correlation between the self-reported time of the 'urge to move' and the onset-time of the effect-primers could be taken as an indicator that the urge reflects the conscious experience of an otherwise unconscious event, i.e., that motor activity induced by the effect-primers reaches consciousness and is interpreted as the intention or 'urge to move'. Evidence for the assumption that the instruction to indicate the 'urge to move' or to report the exact time at which an intention to move becomes conscious is indeed very vague can also be found in the results of this thesis. After the free-choice test-phases of Experiments 1, 2, and 3 participants were asked if they had the feeling that they freely chose to press the keys. The answers to this question were very inconsistent. Some subjects answered 'yes' and reported that they decided which key to press on each trial. However, others answered 'no', arguing that they were restricted in their choices by the instruction (either because they were only allowed to press one of two keys or because they were not allowed to use a specific strategy). This in itself is an interesting result because it shows that vague instructions, like the one to search for an intention to move or to "freely" choose an action, can be misleading or at least be interpreted in very different ways which makes it difficult to generalize results.

Another alternative interpretation of Libet's results is based on the assumption that the participants in Libet's study did not form an intention to move immediately before each single movement, but rather formed a general intention at the beginning

of the experiment, when they received the instruction. Once this conscious intention (i.e., to perform simple movements at random points in time while watching a clock) has been formed, it can influence subsequent behavior automatically and unconsciously (Prinz, 1997; Goschke, 2003; Goschke & Walter, 2006). According to this interpretation conscious intentions are indirect (not immediate) causes of voluntary actions. Rather intentions are conceived of as constraints, which modulate response selection processes by setting certain stimulus-response bindings into readiness. Thus intentions reconfigure the cognitive system to allow the automatic selection of intention-congruent actions in response to specific trigger conditions without having to form a conscious intention before each single movement (cf. Kunde, Kiesel, & Hoffmann, 2003; Neumann & Prinz, 1987). The results of this thesis show that "freely" chosen actions can be influenced by unconsciously activated effect representations. Conscious intentions in turn modulate which effect- or goal-representations are activated in a given context, thereby biasing which actions are selected.

4.3 The role of the emotional valence of action-effects in action control

In Experiments 1-3 I investigated how unconscious priming by learned action-effects influences response activation processes and free-choice responses. In these experiments action-effects were used which only differed in their sensory (directly perceivable) features. However, in everyday life emotional consequences of actions play an important role in deciding which action to perform. It is therefore plausible that emotional features (and other subjective features) of action-effects become integrated into cognitive representations of actions. Experiment 5 was designed to investigate this question and to examine whether the anticipation of action-effects with different emotional valences influences free-choice actions. In the acquisition-phase free-choice key-presses were contingently followed by positive or negative pictures, which were accompanied by a high or low tone. During the test-phase the effect-tones were presented alone and a free-choice response had to be executed. The results showed that the effect-tones elicited a response bias (i.e., above-chance acquisition-consistent key-choices) only if they were associated with posi-

tively valenced pictures, that is, if they triggered the anticipation of a positive emotional effect. By contrast, if the primed sensory effect features were linked to negative emotional consequences, no response bias was obtained.

At least two explanations for this finding are possible. The first one is that the response-effect (R-E) associations that were established during the acquisition-phase differed in their strength for the negative and positive action-effects. However, this explanation is unlikely because the binding of motor codes and action feature codes is believed to be an automatic process (Elsner & Hommel, 2001). These bindings should therefore be equally strong in both affect conditions. The second possible explanation for the findings of Experiment 5 is that perceiving the action-effect tones elicited different cognitive processes depending on their associated emotional valences. The anticipation of negatively associated effect-tones could have elicited avoidance or withdrawal tendencies, whereas perceiving positively associated action-effects may have facilitated approach behavior (Gray, 1990; Elliott & Thrash, 2002; Davidson, 2001). Approach and avoidance behavior clearly depend on the valence of an anticipated action outcome. Several theories have posited the existence of two basic motivational systems. One system is responsible for facilitating behavior and/or generating positive affect and one is responsible for inhibiting behavior and/or generating negative affect (e.g., Lang, 1995; Gray, 1970). Approach and avoidance systems are believed to constitute a network that mediates immediate affective, cognitive, and behavioral responses to perceived or imagined stimuli. According to Gray (1970) the so-called behavioral activation system (BAS) facilitates behavior, generates positive affect and is sensitive to actual or imagined stimuli associated with reward and non-punishment (i.e., positive/desirable stimuli). It is accompanied by perceptual vigilance for, affective reactivity to, and a behavioral predisposition toward such stimuli. The behavioral inhibition system (BIS) inhibits behavior, generates negative affect, is sensitive to negative/undesirable stimuli (i.e., stimuli representing punishment or non-reward) and mediates withdrawal behavior. How can these two motivational systems explain the data from the test-phase of Experiment 5? The anticipation of positively associated action-effects may have induced an approach tendency towards executing the response which has been learned to bring about the positive effect and which was automatically activated by the perception of the sensory effect codes (i.e., the associated effect-tone). Such an

approach tendency could explain the stronger response bias found for positively valenced action-effects. On the other hand perceiving negatively valenced effect features could have evoked an avoidance tendency, leading to inhibition of the response, which was initially activated by the sensory effect codes, thereby attenuating the prime-induced response bias. This hypothesis could be tested further in an LRP experiment. Here, response activation followed by inhibition should be visible for negatively valenced action-effects but not for positive ones. This approach/avoidance explanation is also in line with research concerning affective styles (see Davidson & Irwin, 1999 for an overview), in which it is assumed that emotions guide actions and organize behavior towards goals with an emotional valence.

As noted above, the results of Experiment 5 indicate that affective features of actions are automatically integrated into action representations. This result is in accordance with earlier studies (Beckers et. al., 2002; see also Hommel, in press). A possible explanation of how action-effects become automatically integrated into action representations is provided by the theory of somatic markers by Damasio (1994) and colleagues. They assume that positive or negative somatic states are created if an action outcome is perceived and that these states become associated with the action representation. Making decisions is based on the anticipation of the somatic states associated with possible actions alternatives. Damasio (1991) proposed that a distributed network of brain structures, including the orbitofrontal cortex, the amygdala, and the somato-sensory cortex, is responsible for the acquisition and usage of such links between actions and somatic markers. This proposal is supported by studies of patients with lesions in the orbitofrontal cortex, who have been shown to make disadvantageous choices, which are assumed to result from an impaired ability to generate somatic markers and to anticipate future emotional consequences of possible actions (Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Tranel, Damasio, & Damasio, 1996). It should be noted, however, that this explanation of how the emotional valence of action-effects might have influenced voluntary choices in Experiment 5 are still speculative. Further experiments are needed to provide direct evidence for this hypothesis. Such experiments should also take into account individual differences in emotional responsivity (e.g., the relative dominance of behavioral approach and avoidance systems; cf. Davidson & Irwin, 1999).

4.4 Conclusion

From a more general perspective, the results of this dissertation are consistent with the hypothesis, that conscious intentions or goals are not always immediate "triggering causes" of specific responses, but rather more indirect causes for actions. Intentions configure the cognitive system such that specific response dispositions are set into a state of increased readiness, which enables the quick selection of appropriate actions in response to specific execution conditions (e.g., Goschke, 1996, 2003; Hoffmann, 1993; Hommel, 2000; Kunde, Kiesel, & Hoffmann, 2003; Neumann & Prinz, 1987). This form of intentional modulation of response dispositions is based on learned contingencies between actions and their effects, which starts from birth and continues throughout one's lifetime. As a result of such learning processes, connections between contexts, actions, and the consequences of actions are formed, which can then be used for voluntary action control. In particular, actions can be initiated by anticipating their effects.

While this is by no means a new idea, the experiments conducted in this dissertation have yielded a number of novel insights into the mechanisms underlying action control. First, it was shown that effect representations do not have to be conscious in order to become effective. Rather, the subliminal activation of action-effects can automatically activate associated actions, which have been learned to produce this effect. Thus at least for the admittedly very simple actions and effects used in the present experiments, one may conclude that responses can be activated by unconscious "goals" (i.e., subliminally primed action-effects). It is, of course, a question for further research under which conditions unconsciously activated goals may also play a functional role in the selection of more complex actions (for evidence that this may in fact be the case see e.g., Bargh, 2005). Importantly, the present results also showed that response activation by effect-primers is in some cases subject to inhibitory or further evaluative processes, which modulate whether or not the primed action will actually be executed.

Finally, it could be shown that the emotional valence of anticipated consequences of actions is automatically integrated into action representations along with other (sensory) features of the actions effect and (presumably automatically) modulates free-choices between alternative actions. Taken together, combining free-choice tasks and LRP measurements with ideomotor approaches as done in this thesis have increased our current knowledge of the mechanisms underlying action control.

Chapter 5

References

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Chapter 6

Zusammenfassung

Einleitung: Unser alltägliches Leben beinhaltet eine Vielzahl zielgerichteter Handlungen. Zielgerichtetes Handeln setzt voraus, dass der Akteur *vor* der Ausführung einer Handlung *weiss*, welchen Effekt seine Handlung haben wird. So betätigen wir den Lichtschalter, wenn wir einen Raum aufhellen möchten. Am Beginn jeder Handlung scheint somit die mentale Repräsentation des erwünschten Zielzustand (d.h. des Handlungseffekts) zu stehen, welcher dann die Selektion der angemessenen Handlung kontrolliert. Daraus ergeben sich zwei Fragen: Erstens, wie entstehen die mentalen Repräsentationen von Handlungseffekten und zweitens, wie werden diese eingesetzt, um Handlungen auszuwählen bzw. zu steuern. Erste theoretische Annahmen zur Rolle von Handlungseffekten bei der Steuerung von Handlungen formulierten Lotze (1852) und Harless (1861; siehe auch James, 1890). Die Autoren gingen von einem zweistufigen Prozess der Handlungskontrolle aus. Zunächst werden, in einem frühen Lernstadium, Handlungen willkürlich ausgeführt. Die Effekte (Veränderungen in der Umgebung), die diese Handlungen nach sich ziehen, werden registriert und eine bi-direktionale Verbindung zwischen Handlung und Effekt wird geformt. Später kann aufgrund des Gelernten die eigentliche Handlungskontrolle erfolgen. Dann führt die Antizipation des Handlungseffekts (über Wahrnehmung oder Vorstellung) zu einer automatischen Aktivierung derjenigen Handlung, die mit dem Effekt zuvor assoziiert wurde (d.h. jener Handlung, die ihn im Lernprozess hervorgerufen hat). In jüngerer Zeit haben experimentelle Untersuchungen gezeigt, dass Handlungen, die zuvor mit bestimmten Effekten assoziiert wurden, durch die Antizipation dieser Effekte aktiviert werden können

(z.B. Elsner & Hommel, 2001; Kunde, 2001; Hommel, 2003).

Fragestellung und Methoden: Trotz erster Hinweise (Kunde, 2004) konnte bisher nicht vollständig geklärt werden, ob Handlungseffekte immer bewusst antizipiert werden müssen, um assoziierte Handlungen zu aktivieren oder ob unbewusste Antizipation ausreichend ist. Desweiteren ist der Einfluss emotionaler Eigenschaften von Handlungseffekten auf die Handlungskontrolle noch nicht eingehend untersucht worden. Diese zwei zentralen Fragen motivierten diese Arbeit. Zu ihrer Untersuchung wurden fünf Experimente durchgeführt. Neben Verhaltensdaten wurden dabei auch elektrophysiologische Parameter mit Hilfe des Elektroenzephalogramms (EEG) erhoben. Erstens sollte untersucht werden, inwieweit subliminal dargebotene Handlungseffekte (d.h. Handlungseffekte, die nicht bewusst wahrgenommen werden) automatisch diejenigen Handlungen aktivieren mit denen sie zuvor assoziiert wurden. Daran schliesst sich die Frage an, ob eine derartige automatische Reaktionsaktivierung durch Handlungseffekte, die freie Handlungswahl beeinflusst. Zur Klärung dieser Fragen wurden drei Experimente (1-3) durchgeführt. Jedes der Experimente bestand aus vier Teilen - einer Lernphase, einer Testphase, einer Wahlreaktionsaufgabe sowie einer Reizdiskriminationsaufgabe (wobei die letzteren beiden, wie auch Experiment 4, zur Kontrolle der Wirksamkeit der verwendeten Reize dienten). Während der Lernphase sollten die Probanden auf ein Startsignal hin eine von zwei möglichen Tasten drücken. Als Reaktion auf den Tastendruck und in Abhängigkeit von diesem erschien ein spezifischer visueller Handlungseffekt auf dem Bildschirm (z.B. linke Taste > Quadrat, rechte Taste > Raute). In der Testphase bestand die Aufgabe darin, nach Erscheinen eines Startsignals eine der beiden, bereits aus der Lernphase bekannten, Tasten, nach freier Wahl zu drücken. Ohne das Wissen der Probanden wurde jeweils vor dem Startsignal einer der beiden Handlungseffekte aus der Lernphase subliminal dargeboten. In den Experimenten 2 und 3 gab es zusätzlich zu dem Startsignal noch einen weiteren Reiz, welcher keine Reaktion verlangte. Nach Erscheinen dieses Reizes sollten die Probanden einfach auf den Beginn des nächsten Durchgangs warten. Die Hypothese war, dass die Probanden in der Testphase vermehrt mit der Lernphase konsistente Tastendrucke ausführen, d.h. wenn die linke Taste in der Lernphase mit einem Quadrat assoziiert wurde, sollte nach der subliminalen Darbietung des Quadrates in der Testphase häufiger die linke Reaktion gewählt werden. Während der Testphase (und der Wahlreaktionsaufgabe) von Experi-

ment 2 und 3 wurde das EEG aufgezeichnet und das lateralisierte Bereitschaftspotential (LBP), ein Mass der spezifischer Reaktionsaktivierung, wurde berechnet. Zur Beantwortung der zweiten Fragestellung der Dissertation, ob die freie Handlungswahl durch emotionale Eigenschaften von Handlungseffekten modulierbar ist, wurde Experiment 5 durchgeführt, welches aus einer Lernphase und einer Testphase bestand. In der Lernphase wurden einfache Handlungen (Tastendruck) mit spezifischen Handlungseffekten assoziiert, die unterschiedliche emotionale Valenzen - negativ oder positiv aufwiesen. Dies wurde mit Hilfe von affektiven Bildern in Kombination mit Tönen erreicht (z.B. linke Taste > positives Bild und Ton1, rechte Taste > negatives Bild und Ton2). In der Testphase wurden nun nur die beiden Effekttöne dargeboten und die Aufgabe der Probanden bestand darin, eine der beiden bekannten Tasten nach freier Wahl zu drücken. Zu erwarten war, dass die mit unterschiedlichen Affekten assoziierten Töne die Tastenwahl unterschiedlich beeinflussen.

Ergebnisse und Diskussion: In den Experimenten 2 und 3 zeigte sich im LBP eine signifikante, mit der Lernphase konsistente, Reaktionsaktivierung nach der Darbietung der subliminalen Handlungseffekte. Dieses Ergebnis demonstriert, dass unbewusst dargebotene Handlungseffekte automatisch diejenige Handlung aktivieren, mit der sie zuvor assoziiert wurden. Unter bestimmten Bedingungen kann eine solche Handlungsaktivierung die freie Wahl von Handlungen beeinflussen, d.h. es kommt zu einer häufigeren Wahl derjenigen Handlung, die auch mit dem zuvor dargebotenen Effekt assoziiert wurde (Experiment 1). Desweiteren konnte gezeigt werden, dass nicht nur sensorische (direkt wahrnehmbare), sondern auch emotionale (subjektive) Eigenschaften von Handlungseffekten mit den sie hervorrufenden Handlungen assoziiert werden können. Zudem wurde deutlich, dass die emotionale Valenz von Handlungseffekten einen Einfluss auf die freie Reaktionswahl hat. In Experiment 5 wurden mit der Lernphase konsistente Reaktionen signifikant häufiger gewählt, wenn der zuvor dargebotene Handlungseffekt positiv assoziiert war. Für negativ assoziierte Handlungseffekte zeigte sich dieser Unterschied nicht. Die Ergebnisse dieser Dissertation bestätigen die Hypothese, dass Handlungen durch die Antizipation ihrer Effekte automatisch aktiviert werden, selbst wenn diese Antizipation unbewusst geschieht (Elsner & Hommel, 2001; Kunde, 2004). Zusammenfassend konnten die Untersuchungen der Dissertation dazu beigetragen, das Wissen über Handlungskontrollmechanismen insbesondere des ideomotorischen Prinzips (James, 1890) zu erweitern.

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Chapter 7

Appendix

Appendix A

Table 7.1: Pictures from the International Affective Picture System (IAPS) used as negative action-effects in Experiment 5.

No of IAPS picture	Valence	Arousal
1274	3.17	5.39
2120	3.34	5.18
2800	1.78	5.49
7380	2.46	5.88
9001	3.10	3.67
9007	2.49	5.03
9041	2.48	4.64
9102	3.34	4.84
9320	2.65	4.93
9561	2.68	4.79
9571	1.96	5.64
9584	3.34	4.96
2900	2.45	5.09
3301	1.80	5.21
2053	2.47	5.25

Appendix B

Table 7.2: Pictures from the International Affective Picture System (IAPS) used as positive action-effects in Experiment 5.

No of IAPS picture	Valence	Arousal
1463	7.45	4.79
1750	8.28	4.10
2070	8.17	4.51
2311	7.54	4.42
2341	7.38	4.11
8500	6.96	5.60
5660	7.27	5.07
5700	7.61	5.68
7325	7.06	3.55
7330	7.69	5.14
7470	7.08	4.64
1440	8.19	4.61
1710	8.34	5.41
7270	7.53	5.76
4250	6.79	5.16

FRAGEBOGEN

1. Konnten Sie erkennen, aus wie vielen und welchen Elementen das Figurengemisch zu Beginn eines Durchgangs bestand?

(Wenn ja, erklären Sie bitte kurz was sie erkennen konnten.)

Ja

Nein

2. Wurden alle Elemente des Figurengemischs gleichzeitig dargeboten oder kam eines etwas später oder früher?

gleichzeitig

eine später

eine früher

3. Hatten Sie das Gefühl, die Tasten nach dem Kreuz frei gewählt zu haben?
(Wenn nein, warum nicht?)

Ja

Nein

VIELEN DANK !

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Hiermit versichere ich, dass ich die vorliegende Arbeit ohne unzulässige Hilfe Dritter und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe; die aus fremden Quellen direkt oder indirekt übernommenen Gedanken sind als solche kenntlich gemacht. Die Arbeit wurde bisher weder im Inland noch im Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde vorgelegt.

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Juliane Wendt-Kürschner