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THE COGNITIVE REPRESENTATION OF ACTION: MODULATION EFFECTS BETWEEN ACTION AND PERCEPTION AS MEDIATED BY THE EVENT CODING

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ABSTRACT

The present study was aimed at investigating the nature of the cognitive representations of action, which likely underlie the modulation effects of the action upon other cognitive processes such as attention, memory, and perception. To this aim, the theoretical framework provided by the Theory of Event Coding (TEC) has been taken into consideration. Such a theory accounts for the action-perception relationships by suggesting that perception and action planning are functionally equivalent, inasmuch they internally represent external events. However, only few studies exist that empirically support the validity of this recent model, especially as far as the action-onto-perception modulation effects are concerned. In the present study, some of the predictions of the theory were tested, by addressing whether both planning an action and observing an action bias the perceptual system favouring the processing of the stimulus dimensions that are most suited for that action. Such an expected result is critical as it derives directly from the assumption that the products of both action planning and perception are coded in a common representational medium. In two series of experiments, participants were required to plan, or merely observe, either a grasping or a pointing action. Then they were required to attend to stimuli varying on either the size or the spatial location dimensions. According to the main hypothesis, findings showed that both planning an action and observing an action prime the perceptual processing of action-relevant stimulus dimensions.

Results of this study support the Theory of Event Coding as a comprehensive theoretical framework that can provide the cognitive neurosciences with an efficient cognitive model.

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1. INTRODUCTION

1.1 Overview

In recent years, the theoretical and methodological connection between cognitive psychology and cognitive neurosciences has led to an extensive re-evaluation of the role the action systems have among the other cognitive processes, as attention, memory, and perception. Such an interest for the action components of the cognitive experience has arisen out of a growing body of experimental evidences showing the involvement of the action system, defined in terms of task demands or intended goals, in the earlier stages of the cognitive information processing. For instance, task demands have been found to affect the attention allocation. Specifically, when individuals were required to reach a relevant stimulus with their right hand, the interference of distractor stimuli was found to depend on their proximity to the reaching hand (Tipper, Howard and Houghton, 1999). Also, task requirements and intended goals have been showed to modulate the attention involvement in the visual and auditory spatial coding processes (Ferlazzo *et al.*, 2002). Within the domain of memory, evidences for a further component of the visuo-spatial sketchpad (VSSP) of working memory, dealing with the memory of movements, have been provided as well (Smyth & Pendleton, 1990; Woodin & Heil, 1996). Furthermore, studies of visual perception showed that requiring participants to perform a hand movement modulated the perception of the apparent motion of dots that were displayed on a computer screen (Wohlschlager, 2000). Similar action-related modulation effects have also been showed in both perception of ambiguous figures tasks (Bernstein, Cooper, 1997) and mental rotation tasks (Wohlschlager, 2001). Support for a more dynamic interplay between the action and the other cognitive systems comes from neurophysiologic evidences as well. For instance, some classes of neurons have been observed in the prefrontal cortex of non-human primates that responded when the animal either performed an object-directed action or watched the same action performed by the experimenter. Such evidences have been interpreted in favour of a functional coupling of the perceptual and the motor systems that underlies the internal representation of a set of potential actions that would mediate the performing, the imitation and, perhaps, the understanding of behaviour (Gallese *et al.*, 1996; Di Pellegrino *et al.,* 1992). Indirect proofs for the existence of such a "mirror system" in human beings have been also reported (Rizzolatti and Craighero, 2004 for a review).

Despite the great deal of empirical evidences, the nature and the functional meaning of the interactions between action and perception are still a matter of debate, especially with regards to the functional and the anatomical mechanisms by means of which the action systems modulate the cognitive information processing. Representational mechanisms and motor programming have been claimed in turn to account for such action-on-perception modulation effects. Indeed, there is a growing agreement in considering all these effects as depending on the activation of stored knowledge about the action an individual can perform when interacts with the environment around (Rizzolatti and Craighero, 2004; Tucker and Ellis, 2004; Hommel *et al.*, 2001). From an anatomical point of view, such activation has been ascribed to the involvement of the "mirror system". From a cognitive point of view, most of these evidences emphasize the active involvement of the action systems in the behaviour control, although a homogeneous framework is still lacking that provides all these studies with a comprehensive theoretical account. In particular, both the functional-anatomical properties of the mirror system and the empirical data showing a bi-directional link between the action and perception support the idea that some sort of internally integrated structures exist. However, some important issues are still unanswered with regard to the content and the genesis of such internal representations. For instance, are some semantic-, emotional-, auditory- information encoded in such integrated entity? How are the perception and action features encoded by the cognitive system, in order to form the internal representation? It appears that a comprehensive cognitive model is needed in order to providing the cognitive representation of action with a theoretical structure whose predictions can be experimentally tested.

Indeed, the interest for the action system as an active determinant of the cognitive behaviour represents an old concept in the domain of the cognitive psychology, and some motor theories have already been proposed (Scheerer, 1984). For instance, in the 19th century, Lotze (1852) tried to account for the spatial cognition by formulating a motor theory of perception. In his view, the combination between both the sensorial information (qualitative system of the sensorial experience) and the movement information (oculo-motor system and muscular feelings) yields the spatial experience. The value of such a theory is well shown by its ability to account for even the present-day experimental research on the cognitive psychology of action. However, the study of the action systems has been dropped in favour of the visual perception investigations. This was probably due to the vision-related parameters being easier to handle. Indeed, whilst scientists were able to study visual perception by capitalizing on some elementary properties of the visual stimuli such as contrast, frequency, luminance, and so on, on the other hand, they could hardly operationalize and manipulate those internal and external states that trigger a motor behaviour, due to the lack of suitable recording techniques. Through the 20th century, in spite of the technological progress both the input inaccessibility and the output intractability of the action construct has thrown the psychology of action study into the shade. Consequently, a theoretical re-formulation of the cognitive activity in the terms of the Human Information Processing paradigm has gained acceptance. Within this paradigm, the action only concerns with the final step within the stimulus processing flow (Haggard, 2001). It is worth to note that even though the HIP paradigm has incurred a broad reviewing process (e.g., Miller, 1988; Miller, 1982; Eriksen and Schultz, 1979; McClelland, 1979), its description of the human mind as a biological calculator is still implied in most of the cognitive psychology and cognitive neurosciences literature. Nevertheless, as mentioned above, the accumulating evidences from different domains of the cognitive psychology, which show a crucial role of the action system in determining the cognitive performance, strongly contrast with the heuristic strength of the Human Information Processing model. Indeed, some methodological and terminological troubles, subtending the further specification of the construct of action, still hinder a comprehensive picture of the observed action-perception interaction effects. In particular, some studies showed that task requirements modulate the perceptual performance, and some others showed that also the motor programming modulates the attention allocation (Rizzolatti *et al.*, 1994). Hence, what deals the action with?

Intriguingly, the study of the cognitive representation of action would be largely improved from the further specification of the construct of action. Therefore, a cognitive model that aims at providing the study of the cognitive representation of action with a theoretical framework should clearly define which component of the action the model is actually dealing with. That is, do the actions deal with either simple sequences of motor commands or intended goals, or with the motor programming or something else? The further definition of these issues would make possible to manipulate directly the effects of the action on the other cognitive processes, and hence would allow specific hypotheses about the nature of the cognitive representations to be tested.

The main goal of the present work is to give an experimental contribute to the evaluation of one of the most recent cognitive models that deal with the internal representation of action issue, say the Theory of Event Coding (Hommel *et al.,* 2001). In particular, the Theory of Event Coding (TEC) provides a theoretical framework for linking perception and action-planning by suggesting the functional equivalence between the two systems, inasmuch they internally represent external events (Hommel *et al.,* 2001). The core assumption holds the cognitive action representation as anticipation of its perceivable distal effects. Thus, the to-be-perceived and the to-be-generated events are assumed to be coded and stored together in a common representational domain (Prinz, 1997; Prinz, 1990). In particular, the common representational system entails some patterns of facilitation or interference effects that account for most interaction effects reported in the cognitive psychology literature. In this view, the bi-directional mapping effects between motor and perceptual representations are interpreted as depending on the common coding of motor and perceptual features in the event file. Thus, by stressing the representational aspect, the model allows specific predictions to be tested, especially with regard to the influences of the action planning on the perception. Though, even if the Theory of Event

Coding appears to address the aforementioned threatening issues, still it suffers the lack of an extensive experimental validation.

Here, the presented studies aimed at accomplishing two goals. First, they addressed a deeper investigation of the cognitive representation of the action within the theoretical framework offered by the Theory of Event Coding.

Second, it has been attempted to develop an alternative experimental paradigm aimed at directly investigating the effect of the action on the cognitive processing, for coping with the methodogical problems concerning the experimental manipulation of the action components.

In particular, it will be presented a background of the studies that reported dynamic interaction among the action and the cognitive systems, in order to stress how progressively the action-related system has been revaluated among the cognitive processes to the point that it has reached the status of a cognitive process itself. Specifically, such a review aimed at showing how the importance of the role of the action in the cognitive information processing gradually developed in the literature until the modern theories that see all the cognitive processes as action-oriented. Especially, such a development will be analysed with regard to the nature of the cognitive representation that shifted from being exclusively object-centred to being more comprehensively action-oriented.

1.2 Object-centred representations: Classic views on Action and Perception

Since recent years, much more interest has been traditionally devoted at investigating the extent to which cognitive processes, such as attention, memory and perception, affect the action systems, compared to the inverse modulation effects of the action systems upon the cognitive processes. The reason for such a traditional lack of interest for the action component of the cognitive experience probably lies in the Human Information Processing (HIP) paradigm being greatly influential on most of the experimental production within the cognitive sciences over the last 30-40 years. In particular, only a few studies have been addressed at directly investigating whether and how the actions an individual performs modulate the perceptual or attentional processing of the incoming stimuli. Indeed, depending on how the concept of action is defined, the action systems can be easily considered as capable not only of controlling action planning and execution, but also of modulating the activity of the perceptual system. For instance, if action is defined as an intended goal it might be argued that the task of taking a note of a phone number on a paper sheet would lead to the selection of all the objects having, besides other things, a thin cylindrical shape that, in everyday life, looks like a pen. At the same time, the attentional system should inhibit all of the distractor stimuli that are not relevant for the intended action. This is just one example showing how the action can affect the processing of the perceptual information. Also, the action could be thought to exogenously affect the perceptual processing, as in those situations where there is not a clear intention to act: for instance, one might perceive a stimulus as dangerous, due to the knowledge provided by a negative past interaction with the stimulus itself. However, these considerations appear to be purely speculative (or even trivial in some case) because different inferences about the influence on the perceptual processing by the action system can be derived simply by manipulating the meaning of "action". Specifically, what does the "action" deal with? Is it a simple sequence of motor commands, an intended goal, the knowledge about the action-effects, the action the objects summon, or something else? As mentioned in the overview, methodological problems in defining the construct of action have led many authors to drop the motor theories proposed by the so-called psychologists of action and favour the HIP as the theoretical paradigm for understanding the functional architecture of the cognitive system. The core principle of the Human Information Processing paradigm is well-expressed through the computational metaphor. According to the well known statement of the Human Cognitive Processing theorists that hold the human brain as appropriately modelled as a computer, the cognitive system would process the information through a set of computational functions, that operate serially from the input to the output through a sequence of functional stages that produce, finally, the response or the achievement of the intended goal. In other words, the information processing proceeds from the sensory input to the motor response, from perception to action. In this classic view, the movements and the action systems that control them represent the last stage of the information processing, hence logically ruling out every modulation effect on the perceptual stages by the action systems. Similarly, such an approach to the human cognitive processing posits the functional independence between the perceptual and the action systems.

The theoretical influence of the Human Information Processing stimulated a great body of empirical (but also clinical) studies mainly aimed at investigating the information processing features, before the response selection occurs. This is especially evident in the classic studies on selective attention. For instance, one of the first theories consistent with the cognitivistic view was proposed by Donald Broadbent in the fifties. In particular, both the attentional filter model and a number of the following attention theories were aimed at answering the crucial question of whether attention controls the build-up of perceptual information, or merely selects among the responses associated with currently active percepts. In other words, where does the locus of attention stand, earlier or later with regard to the perceptual processes (Kanheman and Treisman, 1984). Early selection theories, such as the Broadbent's model, held that the attention serves as a filter that selects which one of a number of stimuli will be further processed and stored in the long term memory. Broadbent's (1958) 'filter' model of attention was based on empirical data provided by the dichotic listening task (Cherry, 1953). In the most famous experiment, the participants were presented dichotically, through head-phones, with pairs of digits and were instructed to report them in whatever order they preferred. A strong preference was shown for reporting the digits ear-by-ear, rather than in the order they had been physically presented. Switching attention from one ear to the other seemed to be rather difficult to the participants. Broadbent suggested that stimuli are selected according to their physical attributes, and unattended messages are not further processed and are discarded. It is worth to note that the first theorizations assume the perceptual processing as being only driven by the relevant information, whereas the irrelevant information does not receive any kind of cognitive processing. In terms of the internal representation that potentially controls what kind of further processing the stimuli undergo, it seems plausible that the content of such a representation is only concerned with the relevant information needed to object recognition processes. Intriguingly, such inference seems to depend on the action being merely considered as a the emission of the appropriate response, or in other words the output of a cognitive information processing that solely deals with the recognition of the stimuli. Later studies provided contrasting data with this assumption, by showing that it is possible to switch attention from one ear to the other, if the meaning of the unattended message is relevant to the shadowed message. For instance, experiments by Treisman (1960; 1964; but see also Moray, 1959) demonstrated that participants were able to select which message to attend to by following the meaning of the sentences. This suggests, contrary to the predictions of the original Broadbent's model, that individuals can select a stimulus according to its meaning, not only according to its physical features. More importantly, it implies that the unattended, say the irrelevant, information, yet receives some sub-threshold processing. In particular, the lately revised selection theories attempted to copy with the weakness of the classic filter model by maintaining that selective attention operates after all the stimuli are semantically processed. For instance, Treisman (1960; Kahneman and Treisman, 1984) accounted for these findings by formulating the 'attenuator' model, which shift the filter later along the information processing stages. She proposed that the filter described by Broadbent is actually more flexible, and that the unattended message can be partially semantically processed. Later on, findings reported by Deutsch and Deutsch (1963) formed the first account of a true late selection theory, proposing that all the stimuli are fully processed, and that the attentional process merely selects the stimulus to respond to. The progressive shifting of the locus of the selective attention towards the late stages of the linear processing flow depicts well the difficulty of describing the role of the action with respect to the other cognitive processes (Treisman & Gelade, 1980; Treisman *et al*. 1999; Deutsch & Deutsch, 1963; Broadbent, 1971). Furthermore, it is worth to note that such theoretical and empirical evidences reveal not only the existence of dynamic relationships among different cognitive systems such as attention and perception (i.e. does the selective attention operate early by selecting the relevant information for the perception, or late by selecting the product of the perception?), but also a more complex relationship between the cognitive systems and the action systems. Why, for instance, is the irrelevant information processed? By assuming that all the information is processed in parallel, which kind of internal structure does control whether to enhance or to attenuate the information? With regards to this issue, Kanheman and Treisman suggested that the internal representation of the object, the well-known object-file, would guide the recognition process of the object itself. According to Kanheman and Treisman, all the object features are firstly processed in parallel. Then, the attention operates by binding all the enhanced features in an object file. Finally, the recognition process follows with the comparison of the newly formed object-file with other object representations, ending up with the recognition of the object (e.g., Kanheman and Treisman, 1984). Besides the implications underlying the theory, what it is worth to be noted here concerns the necessary assumption of an internal representation for directing the cognitive information processing. As it will be shown in the following paragraphs, such a kind of object-centred representation has been revisited by some authors in terms of representations action- or goal-centred. These observations suggest the action and cognitive systems to be dynamically inter-connected rather than separate domains hierarchically arranged: more importantly, it might be argued that the meaning of "action" refers to something more than the mere output of the recognition-oriented stimulus processing.

A final note of cautiosness is however needed. Though most of the traditional studies in cognitive psychology refer, explicitly or implicitly, to the serial processing assumption of the HIP paradigm, not all the models proposed in literarature share such a feature. For the sake of brevity, I can just mention PDP (parallel distributed processing) theorists that explicitly negated that the information processing is serially organized, and originated different accounts of information processing, such as the cascade models (e.g., McClelland, Rumelhart, & the PDP Research Group, 1986; Rumelhart, McClelland, & the PDP Research Group, 1986; McClelland, 1979), or the wel known distinction between controlled and automatic processes, the latter being characterized by parallel processing. It is worth to note, however, that the serial processing assumption is still ubiquitous in modern cognitive psychology and cognitive neuroscience research.

The bi-directional interaction between action and cognitive processes has been observed in other different domains besides the attention processes, both in cognitive psychology and in cognitive neuroscience, and raised a heated debate with regard to the nature of the link between the action and the cognitive systems. Nevertheless, within the selective attention research field most of the results have been obtained that still feed the controversial issue of the role of the action system with respect to the cognitive information processing. Moreover, the attention research domain has directly to cope with the internal representation issue, and the role the action, meant here as motor programming, plays within such representations. For instance, one crucial point that is still partly debated by attention scientists is whether the selective spatial attention is dissociable from the oculomotor system, or is a property of it (see Posner and Cohen, 1984; Klein, 1980; Rizzolatti *et al.*, 1994). For this reason, the next paragraph will present a brief review of the studies in the domain of the visuo-spatial selective attention that have shown an interaction between the attentional system and the action systems, supporting the idea of a strict link between action and attention. As it will be described, several experiments support a model defined in terms of a dynamic interplay between the two systems, though a broad agreement still misses on the nature of their link. Generally, the lack of specification of the relationships between the systems can be ascribed to the ambiguity of the construct of action, as well as to methodological problems due to the experimental paradigms employed. Specifically, the understanding of the role of the action in the information stream is hindered by the linearity assumption of the processing underlying most of the experimental paradigms used in the spatial attention studies. Intriguingly, the attention (perception)-action link is based on the observation of bidirectional modulation effects; although some bidirectional effects have been reported, it is also evident that a valid experimental paradigm is needed that not implicitly assumes the linearity of the cognitive processing, in order to actually demonstrate a modulation on the attention by the action. The implications of such studies will be discussed.

1.3 Action-centred representations: The spatial selective attention studies

As mentioned above, one intriguing topic within the study of the visuo-spatial selective attention deals with the investigation of the anatomical and functional relationships between the attention and the action systems. It is worth to note that the first experimental studies of attentional orienting in the visual space were aimed at investigating the hypothetical dissociation of the attention system and the oculomotor system, that is the anatomical structure in the encephalic brainstem subserving the eye-movements control (Posner, 1980; Shepherd *et al.*, 1986; Klein, 1980). Specifically, the attention theorists addressed the study of the *overt* orienting and *covert* orienting (shift of the spatial attention with and without eye-, and/or head-movements, respectively) in order to examine whether the attentional orienting was dissociable from the eye-movements. The Posner experimental paradigm for the study of spatial attention generated several behavioural findings that generally supported the idea of a functional dissociation between the attentional system and the oculomotor system (Posner, 1980; Shepherd, Findlay, Hockey 1986; Cheal and Lyon, 1991; Reuter-Lorenz and Fendrich, 1992). Technically, within the Posner paradigm, participants are presented with a spatial cue that signals the spatial location where the target, with a certain probability, will occur. Participants are instructed to press a response-key as soon as they detect the target stimulus. Typically, two conditions are compared, say valid trials and invalid trials, depending on the spatial correspondence or non correspondence (respectively) between the spatial cue and the target. The benefit in the valid trials, expressed by the reaction times on the valid trials being faster compared to the reaction times on the invalid trials (cueing effect), represents a measure of the spatial attention shift (Posner, 1980; Posner and Cohen, 1984).

Within such a view, the attention system was approached in terms of a cognitive process which is separate and independent of the motor system. As the internal representation as concerned, the empirical evidences provided by the spatial attention investigations support the idea about the existence of object-centred internal representation. Indeed, the Feature Integration Theory suggested the spatial attention being the responsible mechanism for the binding process of the features into the object-file (Treisman, 1964; Kanheman and Treisman, 1984). Specifically, the spatial attention would operate by binding the all features within the selected spatial location. For instance, the illusory conjunctions phenomenon, say the recombination of the registered features occurring when the focused attention is prevented, shows the crucial role of the attention in the integration feature binding (Treisman and Schmidt, 1982). Accordingly, one might argue the involvement of the spatial attention within the cognitive processing yielding the object recognition, and consider the mechanism controlling the allocation of the attention resources as guided by an internal object-centred representation.

As mentioned above, different and contrasting data, as well as methodological confoundings in several studies, support instead the idea that attention and action are functionally and anatomically identical, if only one gets rid of the serial processing assumption and limits the meaning of action to the motor programming. Intriguingly, one might argue the necessary redefinition that such a different statement about the relationships between attention and action entailed upon the nature of the internal structure that potentially guide the allocation of the attention resources.

In particular, although the Posner paradigm provided the broader experimental basis sustaining the spatial shift of attention, the sequential structure underpinning that paradigm threats the reliability of the theoretical interpretations in terms of a functional distinction between the attention and the motor system. In other words, the setup of the Posner paradigm, assumes that the motor response (either response-key press, or saccadic eye-movement, or something else) follows the shift of the attention. But such an assumption implicitly feeds the hypothesis that the investigators of the spatial attention are trying to investigate, thus raising a methodological trouble. Indeed, if no difference were observed between the reaction times on the valid and invalid trials, then one could infer that the attentional system is actually a visual property of the oculomotor system (more precisely, that individuals cannot direct their attention toward spatial location they are *not* fixating).

Intriguingly, by employing the same experimental paradigm Rizzolatti and colleagues provided evidences supporting the functional and anatomical identity between the visual attention and the oculomotor-system, as described by the Premotor Theory (Rizzolatti, Riggio, Dascola, and Umiltà, 1987; Rizzolatti, Riggio and Sheliga, 1994). According to the Premotor Theory, the attention represents a phenomenical property of the motor systems. The theory gained most of its euristic value by explaining two specific effects often reported in empirical studies of visuo-spatial attention: the distance effect and the meridian effect. The distance effect refers to the reaction times on the invalid trials slowing down as the distance between the target and the fixation point increases (Shulman and Remington, 1979; Tsal, 1983); conversely, the meridian effect refers to an increment of the reaction times on the invalid trials, when the crossing of both horizontal or vertical visual-centred meridians is involved (Downing and Pinker, 1985; Hughes and Zimba, 1987; Schmitt, Postma, De Haan, 2000). A hypothesis suggesting the existence of an independent and supramodal attentional system cannot easily account for these effects: in particular, either the hypothesis of the attentional gradient and the hypothesis of inter-emispheric transfer failed to account for the slower reaction times on the invalid trials in correspondance of both the peripherical and the central spatial regions along the visual meridian (Downing & Pinker, 1985; Hughes & Zimba, 1987; Hughes & Zimba, 1989).

According to the main assumption of the premotor theory, the spatial attention must be viewed as embedded within the very same motor and sensorial cortical areas that control the programming and the execution of the motor responses: in other words, the spatial attention appears to depend on a programmed action, before its execution. In particular, the specific components which the motor program consists of are defined serially and independently one of each other (Rosenbaum, 1980, Rosenbaum *et al.*, 1982; 1984). Especially, the motor program specifies both the <u>direction</u> of the movement, and the <u>distance</u> to be covered in order to reach the target (movement amplitude). Modifying one of these two parameters requires the motor program to be re-programmed, resulting in an increment of the reaction times in those situations where such a change in needed (e.g, on invalid trials). For instance, a change in the movement direction of eyes in a Posner paradigm (for instance, when the target occurs in the opposite visual hemifield with respect to the cued location) requires the motor program to be modified in order to control for a different set of ocular muscles, as well as a re-definition of the distance parameter. Conversely, a change in the movement distance (for instance, when the target occurs at a different spatial location with respect to the cued location, but in the same visual hemifield) only entails a different activation of the same set of ocular muscles: in the former case a meridian effect origins, whereas in the latter case a smaller cost is observed, producing a distance effect. The two attentional effects are well accounted for by considering the action as a motor program, and rejecting the idea of an attentional system anatomically and functionally independent of the structures involved in the motor preparation. Rather, the attention is embodied within the structures that encode the sensory-motor information according to the motor requirements of the single effectors: in this view, the spatial attention is strictly related to the action, or more precisely to the action programming.

Beyond the theoretical relevance of the premotor theory for the understanding the mechanisms underlying the spatial attention deployment, what is more interesting here is that the theory seems to replace a strictly serial model of information processing with a more dynamic view, which assumes the motor and the attention system as strictly intertwined. The attention-action identity entails some consequences on the way the allocation of the attentional resources is dealing with. The attention as framed by the Premotor Theory has believed to be implicated in the coding of the individual’s space: specifically, the perception of the object spatial position would be coded by continuously transforming the sensorial information in motor coordinate systems centred on the retina, the eyes, the head, the shoulder, the arm and the hand, that is in action-centred coordinate-systems.

The logical predictions of the premotor theory appealed more than a researcher that attempts to spread the implication underlying the theory to the other circuitry involved in the coding of either the visual and auditory space, as for instance the head movements, the shoulder movements, or movements of other parts of the body (Bédard *et al,* 1993; Ferlazzo *et al.,* 2002; Rizzolatti *et al.,* 1994). Nonetheless, several behavioural (Buchtel & Butter, 1988; Butter *et al.,* 1989; Ward, 1994; Mondor & Zatorre, 1995; Spence & Driver, 1996; Driver & Spence, 1998; Mondor & Amirault, 1998; Schmitt, Postma, & De Haan, 2000), neurophysiological (Macaluso *et al.,* 2003; Macaluso *et al.,* 2002a; Macaluso *et al.,* 2002b; Macaluso *et al.,* 2002c; Macaluso *et al.,* 2001) and electrophysiological findings (Eimer *et al.,* 2002; Eimer, Cockburn, Smedley, Driver, 2001; McDonald, & Ward, 2000; Teder-Sälejärvi *et al.,* 1999) reported some crossmodal effects between the visual and the auditory spatial shift, which the premotor theory failed to frame into. In particular, it has been shown that the spatial attention can be co-oriented across the visual, auditory and tactile modalities, following spatial cues in different sensory modalities (Butter *et al.,* 1989; Spence & Driver, 1996; Driver & Spence, 1998). Furthermore, task demands has been revealed to affect the allocation of the crossmodal attentional resources: particularly, the spatial attention has been found able to be splitted across the visual and auditory stimuli, in order to accomplish task requirements (Spence & Driver, 1996). According to the assumption of the premotor theory, independent and modality-specific orienting effects should be observed, due to the attention being related to the activity of the structures that code the spatial information in coordinate systems centred on the effector. It is worth to be noted that either the lack of further specification regarding the nature of the relationships between the different attentional systems and the missing referring to some internal representational structures that potentially mediate such interaction effects weaken an explanation in terms of motor programming, as claimed by the proponents of the Premotor Theory.

Considerations like these have led researchers of the crossmodal spatial attention to propose the theoretical account in terms of "separate-but-linked systems" (Driver & Spence, 1998). Such a proposal assumes that the attentional systems are functionally independent with respect to the sensory modality, though they generally show the strong tendency to operate in synergy (Spence & Driver, 1996; Driver & Spence, 1998). However, also in this case the nature and the strength of such a link between the attentional systems is still unclear, so that making the interpretation of the modulation effects on the crossmodal attention allocation by the task requirements hard. For instance, do the task requirements represent the intended goal that guide the attentional behaviour of the subjects? Taken together, all of these considerations again raise the issue about the relationships between the cognitive systems, as the attention in this case, and the action system. Whilst some Authors speak about an undeniable link between the attention and the action systems to the extent that a functional and anatomical identity relation has been described by merely meaning the construct of action as motor programming (Rizzolatti *et al.,* 1987; Rizzolatti *et al.,* 1994), however methodological problems still make such an interpretation unreliable, due to the to-be-testing hypothesis being embedded within the experimental paradigm.

Although the Premotor Theory provided the action system research with an important contribution, further investigations are needed to better understand the dynamic interaction between cognitive systems and action systems by setting up an experimental paradigm that actually allows the influential role of the action to be manipulated. Intriguingly, the Premotor Theory contributed by stressed two important point. The first concerns with the construct of action. It is worth to note how the insufficient explanatory means of the sequential information processing paradigm entail a redefinition of the construct of action in terms of motor preparation: therefore, the action rose from a pure response selection role, to controlling agent of the object perception and space coding. Second, as the motor programming being framed as an important mean of the object perception, the problem concerning the medium of the attention has been raised. In other words, the motor preparation underlies the availability of any sort of internal representation able to direct the attention resources. Although the Premotor Theory misses the further specification of such a representation, however it fairly stimulated the following researches at investigating the medium of the attention, as claimed by the action for selection approach.

1.4 The selection for action view

Recently, the study of the links between attention and action led several authors to propose an account of attention in terms of selection for action (Allport, 1987; Tipper *et al.,* 1999 for a review). The core assumption of such a proposal holds the attention process as a mechanism that selects the relevant information from the environment, and at the same time inhibits the irrelevant information, in order to gain the optimal achievement of an intended goal. In other words, among all of the stimuli that continuously hit the sensory systems, only the information that fits the action requirements will be fully processed: in this view, it is the action that manages the allocation of the attentional resources (Allport, 1987; Neumann, 1987, 1990; Van der Heijden, 1992; Tipper, Lortie & Baylis, 1992; Tipper *et al*., 1999). Consequently, such an approach may be viewed as one extreme example of the theories that shift the attentional filter toward the late stages of the information processing flow, by making selective attention and response selection coincident (Treisman & Gelade, 1980; Treisman *et al*. 1999; Deutsch & Deutsch, 1963). In general, most of the studies within this approach addressed the topic of which kind of action-representation guide the selection mechanism. Within this general context, Tipper and co-workers suggested that some kind of action-centred internal representations mediate the selection of information. Importantly, both the relevant and irrelevant stimuli are assumed to be integrated within such action-centred internal representations. The problem the selection-for-action approach copes with concerns the definition of the specific representation associated with different kinds of sensorial information. Importantly, the core principle assumes that the internal representations are accessed as a function of the behavioural goals. For instance, when the task requires a saccade to a specific spatial location, the inhibition is associated with a retinotopic frame of reference (Abrams & Pratt 1998). On the contrary, when the task requires the detection of the stimulus onset, the frame of reference in which the inhibitory selection mechanisms operated is environment-based (Posner & Cohen, 1984). Conversely, when some mobile objects are encountered, object-based frames are active, and the inhibition can move with the object (Tipper *et al.*, 1990; 1991; 1994). The excitation and inhibition processes have been framed to represent the mechanisms which the attention makes use, in order to select relevant information and to ignore the competing interfering information. Typical experiments aimed at exploring this issue investigated whether an action directed to an object is able to both modulate the selection process of target stimuli that were prominent for attaining the goal, and at the same time to inhibits all the other stimuli that interfere with the correct achievement of the goal. Specifically, the interference effect has been taken as measure for providing insight into the mechanisms by which the selection is achieved (Tipper *et al.*, 1994). In the study of Tipper and coworkers (e.g., 1994) the apparatus consisted of a board wherein a matrix of 3 x 3 keys was embedded, each key being flanked by two light-emitting diodes (LED) of different colour (yellow and red). Participants were required to reach and depress the key adjacent to the red target light, starting from a fixed position, and at the same time to ignore the interfering yellow light that might simultaneously occur near one of the other keys. The critical variable manipulated in this experiment was the location of interfering irrelevant distractor lights. The findings showed that when the distractor light was located between the starting position of the hand and the location of the target light, releasing times were slower than when the distractor light was not located between the two locations (starting and target), and that such an interference effect was larger when the distractor was located near the responding hand than when it was located far from the responding hand. Such a pattern of effects was independent of whether the starting position was on the board side near the subject or far from the subject. These results were taken by Tipper and co-workers as confirming that stimuli which are irrelevant to the participants' behaviour are nevertheless automatically encoded in terms of the actions they evoke in a hand-centred frame of reference. According to these findings, attention would depend on both excitatory and inhibitory processes for selecting the prominent targets by encoding their spatial locations in terms of action-centred coordinate systems. It is worth to note that such a view challenges the classic view, according to which the selection mechanism is entirely based on excitatory processes (Posner, 1980; Posner & Cohen, 1984; Treisman, 1960). Instead, these studies suggest that an inhibitory mechanism acts upon the internal representations of the non-target objects. Accordingly, the inhibition process depends on the distractors' levels of activation. The distractors that compete more for the achievement of the action, as for instance those near the responding hand, will be associated with higher levels of inhibition (Houghton & Tipper, 1994). Following studies have been also carried out to further specify the internal representation of the non-target stimulus, by employing a negative priming paradigm (Tipper, Howard, Houghton, 1998; see Tipper *et al.,* 1999 for a review). The rationale of the procedure was as follows: if the internal representations of distractors are inhibited during the selection of the targets, then the processing of subsequent stimuli that gain access to, or retrieve, the same inhibited representations will be similarly impaired, and hence negative priming effects will be larger for near than for far items (Houghton & Tipper, 1994; Tipper *et al.*, 1992). By using an aforementioned similar board, two displays (the prime and the probe display, respectively) were used in an experiment in which the participants were again instructed on each trial to reach for a key adjacent to the red target LED in the presence of a yellow distractor LED, which they were required to ignore. On the two crucial conditions the probe target could be displayed both at the same location as the prime distractor, or in a different location with respect to any items in the prime display, respectively. A negative priming effect was found due to the reaction times on the former condition being slower than in the latter condition. Importantly, the negative priming effect was larger for distractors closer to the responding hand (Tipper, Howard, Houghton, 1998; see Tipper *et al.,* 1999 for a review).

Certainly, the evidences provided within the selection-for-action approach played an important role in the re-evaluation process of the role of the action system within the cognitive processing of incoming information. First, attention appears to subserve the requirements of goal and intended action. With this regard, specific hypotheses about the mechanisms underlying the selection process have been proposed, and some behavioural measures, as the interference and negative priming effects, have been found to be in fair agreement with the predictions of the model. Second, an appropriate experimental setup has been employed, wherein the action (or better the action plan) actually precedes the processing of the stimuli. Indeed, the intended key-pressing action guided the speeded sensory-motor transformation in a hand-centred coordinate system, putatively operated by the selection process. However, whilst both the criteria for the information selection and the selective mechanisms mediating the attentional process have been described, much less attention has been devoted to the definition of the internal structures that are assumed to guide the selection process. In other words, further investigations should deeply examine the nature of such representations, and attempt to understand which components of the action (plan or program) are embedded in such representations. For instance, one might argue that the intended goal of key-pressing represents the content of the actual internal representation. However, one might also argue that the representation of the motor command sequence for attaining the key-pressing guided the selection process. Moreover, it has been described as the inhibitory representation lasted until the presentation of the probe target stimulus, affecting the detection task: another question to which further investigations have to face to, concerns the extent to which the internal representations are flexible and modifiable, depending on the continuously changing requirements of the environment. As it will be shown in the next paragraphs, the definition of the encoding mechanism of the action features in the internal representation represents a crucial point to understand the most of these unanswered questions.

1.5 Interaction between Action and Perception: The formation of the action-centred representations

1.5.1 The visual stream and the necessary interaction between Action and Perception

So far, the existence of bidirectional modulation effects between the action and the perception systems has been discussed, suggesting a dynamic interplay between the action and the other cognitive systems in the successful achievement of behaviour (Ward, 2002). Despite the great deal of empirical evidences, the nature and the functional meaning of these interactions are still a matter of debate, especially with regard to the relationships between the action and the perception systems. As it has been shown in the previous paragraph, representational issues have been claimed to account for such action-on-perception modulation effects (e.g. Craighero *et al.,* 1998; Rizzolatti *et al.*, 1994; Tipper *et al.,* 1999).

Recently, the bulk of these empirical data has been framed proposing the automatic activation of an internal repertoire of actions that the individual accesses to in order to achieve a successful control of behaviour. Several studies aimed at investigating the automatic visuo-motor routines that would provide the motor system with the appropriate actions for the optimal interaction with the objects in the environment. Along this line of research, a modification of the dual visual systems model (Ungerleider & Mishkin, 1982) has been proposed (Goodale & Milner, 1992) that takes into consideration the relationships between action and perception. Especially, the dorsal system within the visual stream has been framed as a network dedicated to transforming visual information into motor output (Goodale & Milner, 1992; Milner & Goodale, 1995). The original proposal of the dual visual systems framework recognizes the visual system as actually composed of two sub-systems, one for object recognition and the other for spatial processing (Held, 1968; Schneider, 1969; Trevarthen, 1968; Ungerleider & Mishkin, 1982). The first definition of the two sub-systems is usually attributed to Ungerleider and Mishkin (1982) who classified two distinct anatomical streams projecting from the primary visual cortex (V1). One stream projects ventrally to the inferotemporal cortex, whereas the other projects dorsally to the posterior parietal cortex. The two systems were proposed to subserve object discrimination and spatial localization, and thus were labeled "What" and "Where", respectively. More recently, Goodale and Milner proposed that the dorsal system should be named a "How" system rather than a "Where" system.. According to their view, the distinction between the ventral and the dorsal visual systems focuses less on the differences in the information used by the two systems, and more on differences in the way that information is transformed for output. Goodale and Milner's "What" system processes object features for long lasting representations using multiple frames of reference, whereas their "How" system transforms the visual information for guiding actions toward the environment, hence mostly using an egocentric frame of reference. Also other authors have followed a similar approach, proposing separate systems for awareness of objects and visually guided actions, (Bridgeman, Kirch, & Sperling, 1981; Jeannerod, 1997; Rossetti, 1998). Interestingly, Goodale and Humphrey (1998) also suggested that one of the roles of the ventral system is to direct the dorsal system to a suitable target. Once so directed, the target object's parameters will be transformed into motor output automatically, and with minimal influence from the ventral system. Their theory does not deny an influence of the ventral system upon action programming, but assigns it essentially a 'steering' role. Functional knowledge about the appropriate part of a tool to grasp, for instance, could be used merely to direct the dorsal system to that part of the object. Indeed, where knowledge is required to direct the dorsal system to an appropriate object part then concurrent tasks which tax the semantic system also disrupt the accurate steering of the dorsal system (see Creem & Proffitt, 2001).

These models of the organization of the visual system generated a large number of studies addressing the major distinction between the coding of visual information for conscious perceptual judgements and for action (e.g. see Goodale & Milner, 1995; Rossetti & Pisella, 2002 for reviews). For instance, Goodale and colleagues (1994) investigated whether the pointing action was affected by the perceptual judgement. They had participants being required to point to a spatially arranged visual target. In particular, on each trial the spatial position of the visual target was progressively modified, without the participants being informed about it. Goodale and colleagues found the motor response to be unaffected by the target spatial relocation, though participants did not report to be aware that a change of position occurred. Such a finding led Goodale and colleagues to conclude for the independence of the perceptual and action systems, as the motor performance was completely unaffected by the erroneous perceptual judgement (Goodale *et al.,* 1994). A similar behavioural study reported by Castiello and colleagues indicated that the change of hand trajectory occurred more than 300 ms before that participants perceptually detected the spatial relocation of the target (Castello *et al.,* 1991). Moreover, neuropsychological studies described the apparent dissociation between the information available to the perceptual versus the motor system on brain-damaged patients. For instance, Castiello and colleagues (2002) reported the case of a 74 yo patient suffering from a left parietal lesion (due to perinatal injury) who showed a bias when grasping objects: specifically, he persisted in grasping both fixed and moving objects by their left side, though he could still perceive the object as a whole entity. According to the Authors, the left inferior parietal lobe would participate to the motor coding by representing the objects affordances. In the specific case reported, the left inferior parietal lobe would have provided the individual with the affordance-appropriate hand motor configuration suitable to correctly grasp the objects. Also, some neuropsychological studies on patients affected by visual agnosia revealed a dissociation between the ability of conscious visual discrimination and the ability of carrying on appropriate actions. Specifically, agnosic patients have been found to be still able to make correct prehensile actions to objects they nevertheless fail to recognise (i.e. Milner *et al.*, 1991). Similarly, evidences from Aglioti and colleagues revealed similar perception-action dissociation on normal subjects by using the Tichener circle illusion. In this illusion, two identical discs can be perceived as being different in size when one is surrounded by an annulus of smaller circles and the other is surrounded by an annulus of larger circles. They showed that the visual illusion deceived perceptual judgments of the object size, but only marginally influenced the size estimates used in grasping it. In other words, when participants were required to pick up one of the discs, their grip aperture during the reaching phase was largely appropriate to the real size of the target (Aglioti, DeSouza & Goodale, 1995).

Altogether, these empirical evidences show that the sensorial feedback of actions is available to the cognitive system later than the motor feedback. From an adaptive point of view, that the adjustment of the motor performance occurs before than its perceptual awareness grants that a perfomance appropriate to the task demands will be achieved most of the times.

It has also been suggested the subjective awareness of the motor response depends on the representation about the sensorial consequences of the action being available to the actor. More specifically, the subjective awareness has been held to be a function of the discrepancy between the attended sensorial consequences and the actual sensorial consequences of actions

(Blackemore, Wolpert & Frith 2002). More precise definitions of the internal representation consistency, as well as of its complex relationships with the subjective awareness, have been proposed within two different models: the forward and the inverse model. The first one assumes that the action representation always contains an efferent copy of the motor program: specifically, such an efferent copy would inform the central nervous system about the sensorial consequences of that action, before the motor output is emitted. In this sense, the conscious awareness is thought to depend on the ability of anticipating the action effects. Conversely, the inverse model posits that the cognitive representation of the action effects drives the motor programming and the motor output (Blackemore Wolpert & Frith 2002). Besides the specific aims of this series of studies, what it is intriguing here is the appealing concept of an internal representation that drives the intended behaviour by anticipating the action effects. However, all of these approaches to the study of the internal representation of action sustain the independence of the perception and the action system, though a clear overlap and a precise mapping between the two systems have been often referred to, as it will be shown later on.

Altogether the studies that have provided empirical evidence favouring the distinction of two different visual pathways, one for the conscious perception and one for guiding the action, lead to argue for the existence of different internal representations underlying the perceptual experience and the visuo-motor behaviour (Mack & Rock, 1998; Milner & Goodale, 1995; Jeannerod, 1997). For instance, Jeannerod (1997) proposed that "[…] actions are driven by implicit ‘knowledge’ of object attributes, such that stable and decomposable motor patterns arise to cope with external reality." (p. 51), and proposed a distinction between semantic and pragmatic representations. The semantic representation involves the integration of the elementary features (colour, contrast, depth) of an object into higher-order properties (volume, form) that ultimately allow a percept to exist as a meaningful entity. According to Jeannerod, such integration occurs at different levels. For example, the form must be first extracted from the contours and the contrast; further processing allows for the attribution of semantic or contextual properties to the object. Conversely, the pragmatic representation consists of the rapid sensorimotor transformations involved when treating the object as a goal for an action (Jeannerod, 1994; 1997). The object attributes are only represented to the extent that they elicit specific motor patterns for the body. Moreover, a specific reference is made to the different frames of reference that are potentially needed to represent objects, depending on the goal of the observer (see also Tipper *et al.*, 1999). However, the internal representations proposed by Jeannerod go beyond the anatomical distinction between an object recognition pathway and a visually-guided object-directed action pathway. According to Jeannerod "a subject is rarely acting *or* perceiving" and most of the time individual use both the modalities simultaneously. Furthermore, the "perception involves a great deal of unconscious functioning and does not always lead to immediate conscious experience, while actions are far from being always automatic (they involve representations to the same extent as perception does)" (Jeannerod, 1999). Thus Jeannerod concludes for a task-dependent view of the visual information processing, where "neural subsystems for analysis of visuospatial cues, object identification, estimation of context, visuomotor transformation, generation of the proper movement, etc., are assembled with each other according to the needs of the task, using resources from ventral and dorsal pathways in both hemispheres. The resulting distributed neural representations revealed by neuroimaging studies are endowed with predominantly "pragmatic" or "semantic" functions, with "pure" action or "pure" perception at the two extremities of the spectrum" (Jeannerod, 1999). Later, the same Author proposed the existence of a covert state of the action, that is a sort of cognitive representation of the action that includes both the means to reach the intended goal and the consequences on the environment of that action. Such a kind of S-states (as the covert states of the action have been called) involve the activation of distributed neural networks as a function of the intended action. Actually, the S-state simulates the brain activity observed during the same, executed action. Some of them are accompanied by a conscious experience, some others are not, but in general they all bear the same relationship to the action at behavioural and neural level (Jeannerod, 2001).

Several other empirical evidences gave a more complex picture of the relationships between action and perception. For instance Pavani and colleagues (1999) re-interpreted the findings reported by Aglioti, DeSouza and Goodale (1995) by showing that both the perceptual estimation and the hand shaping were similarly affected by the Tichener circles illusion. Specifically, they argued that the perceptual and the grasping tasks in the Aglioti and colleagues experimental setup were not balanced with regard to the influence of the circle arrays on the two tasks. In fact, on the perceptual task the participants compared two discs in order to judge the relative size of the target stimulus. On the contrary, on the grasping task, after the target was selected, only one visual configuration influenced the motor response. By asking participants to estimate and grasp a disc centred in a single annulus of Tichener circles, Pavani and colleagues were able to show the aforementioned interaction between action and perception (Pavani *et al.,* 1999). Other studies suggested that the dissociation between the functional pathways for the perception and the action is only found when specific experimental requirements, for instance the allocation of attentional resources (Mack & Rock, 1998), have to be met. A crucial role appears to be played by the delay between the visual presentation of the target stimulus and the relevant movement initiation. Several studies performed on healthy subjects (Creem & Proffitt, 1998; Bridgeman, Peery & Anand, 1997) and neuropsychological patients (Rossetti, 1998) showed that with long delay the conscious perception affects the motor response. These findings illustrated that when the motor memory fails, the motor system must necessarily rely on a stored representation to inform its action. A recent case study with an optic ataxic patient provided evidences showing that the intact cognitive system can supplements the impaired motor guidance system. Specifically, the optic ataxic patient AT could not accurately grasp a neutral object such as a small cylinder. However, her grasping improved significantly when the neutral object was replaced with a familiar cylindrical object such as a tube of lipstick (Jeannerod *et al.*, 1994). To summarize, all these data appear to show a necessary interaction between the conscious perception and the motor guidance systems, in order to accomplish the successful interaction between the individual and the object, so that, for instance, a graspable object is transformed in the appropriate hand shape for grasping that object.

1.5.2 The affordance effect

As discussed above, several studies aiming at investigating the interdependence of the conscious perception and the motor guidance system provided evidences for a visuomotor link between the mere object observation and its translation into the appropriate hand shaping for the successful interaction (Milner & Goodale, 1995; Pavani *et al.,* 1999; Craighero *et al.,* 1996; 1998; Tucker & Ellis, 1998). It has been discussed so far how, for such visuo-motor transformations to occur, the physical characteristics of the objects, such as size, shape and location, must be firstly selected and enhanced with respect to the other irrelevant features. Then, the visuo-motor transformation process occurs by configuring the hand accordingly (see Jeannerod *et al.*, 1995; Milner & Goodale, 1995). There seems to be a large convergence on the fact that several kinds of internal representations might guide such a kind of transformational processes. Moreover, there is a large agreement that such representations deal with the appropriate object-related hand movement rather than with the object visual recognition (see Craighero *et al.*, 1998; Rizzolatti *et al.*, 1994; Tipper *et al.,* 1999).

Specifically, a specific pathway, or some stored knowledge about the object-hand interaction, should manage the relevant information selection, its processing, and finally the matching between the object features (say, shape, size, location) and the hand configuration shaping (say, grip aperture, direction and so forth). By emphasising the linkage between perception and action, Fagg and Arbib (1998) proposed the FARS (by the contributes of Fagg-Arbib-Rizzolatti-Sakata) computational model, where the circuitry of the visuo-motor transformations for the control of grasping are specified. The model is based on findings suggesting a close relationship between the anterior intraparietal sulcus area (AIP) of the posterior parietal cortex and the F5 area of premotor cortex in monkeys trained to grasp objects. Interestingly, it posits a distributed code for the *affordance*s having a role in grasping objects (Fagg & Arbib, 1998).

Whilst such a model stressed the action-related rather than the object recognition-related nature of the internal representations, other studies addressed the behavioural effects caused by the direct route from vision to action. These behavioural effects are based on the reported potentiation of some compatible action representations, after the observation of the visual properties of the objects for which those action are mostly suitable (Craighero *et al.,* 1996; 1998; Tucker & Ellis, 1998, 2004; Ellis & Tucker, 2000; Grèzes, Tucker, Armony, Ellis and Passingham, 2003). Accordingly, it has been shown that the mere observation of some categories of objects elicits automatically the activation of their representations (Tucker & Ellis, 1998; 2004; Ellis & Tucker, 2000; Creem & Proffit, 2001). Several studies that have addressed such a visuo-motor priming effect are based upon the extension of the *affordance* concept. The concept of affordance has been proposed by Gibson within his ecological theory of perception. According to his claims, the individual perceives in order to operate on the environment, and hence the perception is designed for the action. In this very general context, the affordances represent the perceivable possibilities for the action, or in other words the potentiality of interaction between the individuals and both the environment and the other individuals. In the terms of Gibson, individuals perceive possibilities for action, such as surfaces for walking, handles for grasping, tools for manipulating, and so forth (Gibson, 1977; 1979). Within the view of Cognitive Psychology, the affordance may be viewes as a particular mental state stemming from the interaction between the organism and the object, mainly referring to the automatic activation of motor representations that are compatible with the most appropriate actions directed to that object.. Within this general view, a broad corpus of evidences has been provided by employing a priming paradigm, showing a link between the observation of an object and the automatic activation of action-related motor representations (Tucker & Ellis, 1998, 2004; Ellis & Tucker, 2000; Craighero *et al*., 1996). For instance, Tucker and Ellis (1998) investigated the visuo-motor priming effect in a series of studies through the use of a stimulus-response compatibility paradigm, using pictures of common graspable objects as stimuli. In particular, they aimed at investigating the relationships between the orientation of an object and the hand most suitable to perform a reach-and-grasp movement to the same object. Participants were presented with photographs of objects having two horizontal orientations (one compatible with a right-hand grasping, and one compatible with a left-hand grasping) and two vertical orientation (upright vs. inverted). The participants were required to decide as fast as possible whether each object was upright or inverted. Findings showed that the participants performed faster right-hand responses when the object orientation was compatible with a right-hand grasp, and faster left-hand reponses when the object orientation was compatible with a left-hand grasp. These results are consistent with the view that observed objects automatically potentiate components of the actions they afford, even without an explicit intention to act (Tucker and Ellis, 1998; Ellis & Tucker, 2000). Similar findings have been obtained in PET studies that showed that either the mere observation, imagination and silent generation of the noun or the corresponding action verb involved specific sets of cortical regions (Grafton, Fadiga, Arbib & Rizzolatti, 1997; Grèzes & Decety, 2002). Furthermore, Craighero and colleagues (1998; but see also Craighero *et al*. 1996) showed that the grasping initiation was faster when the previously displayed visual prime was congruent with the to-be-grasped object. Some other coherent empirical data have been discussed in the above paragraph. However, results from a series of studies reported by Tucker and Ellis seem to demonstrate that the effects of affordance might depend more upon stored knowledge of the object and its associated actions than upon its detailed physical parameters. In their experiments they showed that the congruent matching between object affordances and afforded responses speeded the categorical judgement of artificial or manufactured object images independently of the stimulus exposure time (Experiment 1) and the stimulus degradation (Experiment 2). Moreover, such a visuo-motor priming effect was also found using the names of the objects instead of their images (Experiment 3) (Tucker & Ellis, 2004). In other words, the object affordance effects were evident also in off-line tasks. Also, such findings recall the aforementioned studies wherein the cognitive processing has been found to supplement the failing motor memory guidance (Creem & Proffit, 1998; Bridgeman, Peery & Anand, 1997; Rossetti, 1998). According to these findings, Tucker and Ellis suggested that when the object is not the target of the actual grasping action, the basis for the affordance effect is most likely the stored object knowledge rather than the immediate physical stimulus properties that would guide the action when it was the target of a real action. This action knowledge is only broadly tuned and reflects classes of broadly specified actions in contrast to the finely tuned calibrations that take place during prehensile acts (Tucker & Ellis, 2004).

However, such a consideration again raises the problem of the representational content of the stored knowledge that would guide the individual in the interaction with his environment. As it has been shown, the existence of a sort of internal structures have been necessarily suggested in order to account for the most of the empirical data discussed so far. Behavioural and neurophysiologic observations are consistent with the idea that such internal representations entail the automatic transformation of the visual properties of the object into the motor pattern mostly appropriate to correctly interact with that object. Accordingly, the individual-object interaction appears to be directed by an action-centred internal representation, rather an object-centred internal representation. However, other data suggested the content of such an internal representation being not just restricted to the motor instructions aimed at correctly interacting with the objects, but containing a more broadly tuned knowledge about the object-hand interaction that is independent of the visual presence of the object itself.

Indeed, there is a growing agreement in considering all these effects as depending on the activation of a stored repertoire of actions at the individual's disposal mediated by the mirror system, that it will be closely discussed in the next paragraph.

1.6 The mirror system and the vocabulary of the actions

As it has been discussed, the affordance effect has been ascribed to the activation of a stored repertoire of motor programs mediated by the neural activity of the mirror system. The mirror system refers to a class of neurons in the F5 area of the primate brain that have been found to fire both when the animal performs a grasping action and when the monkey observing at another actor performing the same grasping action These neurons have been directly observed only in the primate brain, and have been called "mirror neurons" due to their visuo-motor properties (Gallese *et al*., 1996; Di Pellegrino *et al.,* 1992; see Rizzolatti and Craighero, 2004 for a review). Such a discovering has been considered as a compelling evidence of the strong link between the action and the perception. Indeed, as the mirror neurons respond for either the execution of an object-directed action and the mere sight of an object-directed action, an anatomical and functional coupling of the perception and motor systems it has been suggested that would internally represents a set of actions potentially mediating the emission, the imitation and, perhaps, the understanding of behaviour (Fadiga *et al*., 2000; Rizzolatti & Craighero, 2004; Fadiga & Craighero, 2004). Indirect evidences for the existence of a mirror system in humans come from neurophysiological and behavioural studies. Specifically, the aforementioned automatic link between the visual properties of observed objects and the specific motor programs which are most suitable to act on them (Grèzes, Tucker, Armony, Ellis and Passingham, 2003; Tucker and Ellis, 1998; Craighero *et al.,* 1996; Tucker and Ellis, 2004) has been interpreted as an "object-related" activation. This "passive activation" is based upon the extraction of the intrinsic visual properties of the object (size, shape and orientation), and the following matching between the extracted visual description and the appropriate action. Such a matching would be operated by the AIP-F5 area circuitry (see Jeannerod *et al.,* 1995 for a review). According to such a neurophysiologic account, the passive activation also occurs when the individual observes a motor action executed by another individual ("action-related" activation). Indeed, the mere observation of actions has been found to affect the response execution (Brass, Bekkering & Prinz, 2001; Edwards, Humphreys & Castiello, 2003). The action-related activation is based on the visual description of the observed action, and its matching with a motor representation of a similar action. These operations also appear to be performed by the mirror system (Rizzolatti & Craighero, 2004). As one can see, a complete system of neural circuitry in the premotor cortex has been described by Rizzolatti and colleagues putatively mediating the storing of the cognitive representation of the actions useful for both the generation and the observation of the actions themselves, though no further specification about the content of such representations has been given. Besides, it is worth to note that the behavioural data supporting the existence of the mirror neuron system in the human being are based on the experimental observation of the behavioural effects stemming from these representations. Accordingly, the representations would entail a neurophysiologic and functional coupling between action and perception system yielding the well-discussed bi-directional modulation effect between action and perception. More specifically, as it has been above reported, both observing the object-directed action or the object itself have been found to potentiate the activation of those action representations that best matched the observed-action or the observed object. Similarly, evidences for the converse motor-visual priming effect have been also reported. It has been shown, for example, that preparing a grasping movement towards a clockwise or counter-clockwise oriented bar influences the visual processing of compatible hand pictures (Craighero *et al.*, 1999; 2002). In their experiments, Craighero and colleagues required participants to prepare a grasping movement on clockwise or counter-clockwise oriented bars. On each trial the participants were instructed to press a response key, and keeping it pressed. While they were preparing the required clockwise or counter-clockwise action, a depicted hand served as go-signal for the grasping initiation. The hand was depicted in a posture that could be compatible or non-compatible with the end point of the to-be-prepared grasping action. Upon the go-signal presentation participants were instructed to release the response key and perform the grasping action according to the task demands. The findings showed the grasping initiation was faster when the response followed the compatible visual stimulus compared to the non-compatible stimulus (Craighero *et al.,* 2002). Interestingly, by using an analogue experimental setting Vogt, Taylor and Hopkins (2003) demonstrated the motor-priming effect reported by Craighero and colleagues depended on the observer’s perspective: in particular, they presented the participants with compatible/non compatible go-signals similar to those used by Craighero and colleagues, though the hand posture perspective was manipulated by displaying pictures of hands that matched the end posture of both the observer’s own hand or in the perspective of another person. Findings showed that only stimuli presented in the observer's own perspective give rise to the advantage in initiating the grasping action (Vogt, Taylor, Hopkins, 2003).

Taken together, such empirical data concerning the expected bi-directional effects between the motor and the perceptual representations associated to the object-directed action, as well as the neurophysiological studies on the property of the mirror system support the view concerning the existence of internal integrated structures that, by producing the functional coupling between action and perception systems, would guide the execution and the observation of the object-directed action. However, as some important issues are still unanswered with regard to the content and the activation modalities of such internal representations. For instance, can semantic-, emotional-, auditory- components be encoded in the integrated whole and prime as well the response execution? How are the perceptive and motoric feature encoded by the cognitive system? As a consequence of this lacking of specification concerning the nature of the cognitive representation of the action, make the integration within such a theoretical framework of some reported behavioural data hard. Indeed, as it has been discussed previously, the semantic information has found to influence the correct grasping hand tools (Creem e Proffitt, 2001). In their experiments Creem and Proffitt asked the participants for grasping some familiar objects, by performing at the same time a spatial task or a semantic task; in the control condition participants did not perform any secondary task. Findings showed that the number of the appropriate grasping decreased when participants were performing the semantic task, compared to the spatial task and the control condition. Such a result indicated the semantic information being integrated in the action representation. Moreover, the functional coupling between action and perception has been found to be active also in off-line tasks, wherein no visual input can guide the action representation activation (Tucker & Ellis, 2004). Also, imaging data from Schubotz and Von Cramon studies (Schubotz, Friederici, Yves von Cramon 2000; Schubotz & Yves von Cramon 2001; 2002; 2003) indicated that abstract sequences of perceptual events, not only observed actions and action-related stimuli, are transformed in motor representations. Specifically, they observed that monitoring abstract trains of stimuli for a timing, color-shape, or location oddball recruits neural circuits in the premotor cortex that are also involved in the control of actions that are specifically related to these stimulus dimensions (i.e., tapping/articulation, grasping, and reaching, respectively). In the Schubotz and Yves von Cramon's experiment (2002), the participants were presented on different blocks with trains of abstract visual and auditory stimuli. Visual sequences consisted of the presentation of circles whose size was alternatively varied: such a manipulation was expected to induce the representation of a sequential hand grip configuration, reflected by the activations within the premotor areas involved in the hand action. Auditory sequences consisted of the presentation of tones whose pitch was varied: such a manipulation was expected to induce the representation of a sequential laryngeal configuration, reflected by the activation within the premotor areas involved in vocal actions. The participants were required to attend to the structure of the presented stimulus sequences, and to decide whether the last three stimuli within each trial matched the expected sequential order. The findings showed that the activity of the premotor areas differed according to the perceptual information to be predicted. In other words, attending to particular stimulus dimensions apparently requires the activation of neural systems that control those actions that would benefit most from stimuli varying on these dimensions. Such a result appear to be consistent with the basic statements based on the anatomical and functional properties of the mirror system. Specifically an immediate mapping of the perception onto the action has been showed, that potentially subserve the structural analysis of sequential patterns. By the other hand, unlike previous studies that have employed familiar objects (see for example Ellis & Tucker, 2000) or action-directed object as a visual stimuli (see for example Craighero *et al.*, 2002), results from Schubotz and Yves von Cramon indicate that also abstract sequences of perceptual events entail the matching of the perception onto the action. The point stands in further understanding the elements that on each moment form the internal representation, in order to predict their behavioural effects concerning, for instance, the converse motor-visual of the action preparation on the cognitive processing of abstract action-related dimensions of the stimulus.

On the next paragraph a recently formulated cognitive model will be presented that, by suggesting a definition of all these aspect, could be aimed at providing the cognitive neurosciences with a more comprehensive theoretical framework for the interpretation and the testing of the behavioural effect rising from the neurophysiologic coupling between action and perception systems.

1.7 The cognitive representation of action: The Theory of Event Coding (TEC)

1.7.1 The event-file concept

It has been shown how the idea of the internal representations of objects and actions has gained a considerable impact, for instance within the domain of visual attention (Kanheman & Treisman, 1984; Tipper *et al.*, 1999; Rizzolatti *et al.*, 1994) (but see people contending that internal representations exist at all, O'Regan, & Noë, 2001). Likewise, some evidences showing the existence of shared mechanisms for action perception and action control from neurophysiological studies have been discussed (e.g., Rizzolatti and Craighero, 2004). However, still many questions need to be answered, especially with regards to the content as well as the modalities which such internal representations are retrieved and accessed through. As aforementioned, behavioural and neurophysiological studies have provided empirical evidence for the existence of long-lasting stored knowledge about either object's appropriate use and action schemata (Tucker & Ellis, 2004; Creem & Proffitt, 2001; Rizzolatti & Craighero, 2004). So far, although many studies have addressed the functional and anatomical links between action and perception, more comprehensive theoretical accounts that fit all of those empirical evidences are still scarce.

Within this general context, the recent theoretical proposal advanced by Hommel and colleagues, the Theory of Event Coding (TEC), may be viewed as a challenging conceptual framework for accounting most of the phenomena and topics raised so far (Hommel *et al*, 2001). The core assumption of the Theory of Event Coding (TEC) holds the functional equivalence between perception and action planning, inasmuch they internally represent external events: in fact, according to the TEC's proponents, perception and action planning are "two alternative ways of doing the same thing", namely representing an external event (Hommel *et al.*, 2001). According to this view, perceiving means actively acquiring information about the perceiver and his environment through a continue perceiver-environment interaction. On the other hand, acting deals with the production of perception: namely, performing an action produces the perception of the effects of that specific action. Thus, if perception deals with perceiving the action, and acting deals with acting the perception, then "there is no theoretical reason to draw a conceptual distinction between anticipating a perceptual event and planning an action, or between actually perceiving and carrying out an action plan" (Hommel *et al.*, 2002). It is worth to note that, as a consequence, the late product of the perception, and the early product of the action, say of the action planning, are taken as constructs of the action and the perception, respectively. The functional equivalence between action and perception entails the to-be-perceived events and the to-be-generated events to be coded and stored together in a common coding format (Prinz, 1997; Prinz, 1990). Thus, one might argue that the individuals generate and perceive events wherein both the action-related and the perception-related features are coded in the same representational format, and where the event is a composite of those feature codes. As described above, the general idea regarding stimuli as being composed of multiple features codes is an old claim in cognitive psychology, and indeed the proponents of the Theory of Event Coding referred explicitly to the object-file concept to sketch their event-file construct. The object-file deals with the problem of the visual perception of objects, with particular regards to their representation in coherent internal structures (Kanheman & Treisman, 1984). Typically, the temporally binding of distributed visual features has been taken as the responsible mechanism for the object representation in the brain (e.g. Conway *et al.*, 1995). Though, a problem with such an account concerns the mechanisms or the structures that control the binding of the features in a integrated whole, which still have to be fully determined. Treisman framed the attentional processes as candidate for the "glue" of such features (Treisman & Gelade, 1980). In her feature-integration theory, she proposed that all the features that are present in the visual field are initially activated in parallel but independently one of each other, thus objects defined by a conjunction of features need a binding process to get fully represented. According to the theory the binding of the relevant features is mediated by the spatial attention being scanning the visual field serially (Kanheman & Treisman, 1984; Treisman & Gelade, 1980). Later on, Kanheman introduced the object-file concept assuming that the more abstract semantic knowledge about an object is integrated in the object-file, including the episodic trace that marks the specific interaction between the perceiver and that specific object (Kanheman *et al.*, 1992). Such a definition of object-file closely resembles the concept of event-file, though the action component has to be included in the latter, in order to fully distinguish it from an object-file. In particular, the Authors referred to the concept of action-file, that is to the idea that the same integrative principle that binds the perceptual features in the object-file governs the action planning. Several studies provided evidences that actions may be considered to be internally represented in the same way as the objects in the object-files (Rosenbaum, 1980; 1987; Schmidt, 1988). For instance, according to Rosenbaum a motor program consists of separate components that are specified and modified in a certain amount of time (Rosenbaum, 1980): given these findings, one may argue that the feature codes the action refers to are bound in the action-file in the same way as the feature codes of perception are bound in the object-file. Evidences showing that the action feature codes are similarly bound in the action file as in the object file have been also provided: most of these studies showed that the learned action effects are integrated in the action planning (Hommel, 1996; Elsner & Hommel, 2001; Kunde, 2001; Ziessler & Nattkemper, 2002), generally by using S-R compatibility paradigm where the complete or partial correspondance between the action effects and the response to be given selectively affects the participants' performance. For instance, in the Hommel's experiments (1996), participants first learned that their responses (different keypresses) produced different effects (high and low pitched tones). Following, they were required to respond to visual stimuli that were simultaneously displayed with one of the response effects. Findings showed that responses to the visual stimuli were faster if the concurrent tone matched the previously learned effect of the required response. Together with other results, these data have been interpreted as evidence for an automatic integration of the motor pattern representing a certain movement and the cognitive pattern representing the effects of that movement in the environment. More important to the aims of the present work is the event file construct: capitalizing upon the way in which the perception-related and the action-related feature codes are glued in the object-file and in the action-file (respectively), and upon the representational medium commonality assumed for action and perception, the Theory of Event Coding claims that both the action-related feature codes and the perception-related feature codes are integrated in the event file by the same cognitive code: specifically, such a cognitive code, say the event code, consists of the codes that represent the distal features of an event. The following paragraph will closely examine the characteristics of such common coding for the to-be-generated and the to-be-perceived events.

1.7.2 The event coding

The common coding approach maintains that the codes that represent the perceptual objects are the same as those that represent the action plans. In particular, the codes representing both the to-be-generated events and the to-be-perceived events refers to the distal features of an event, not to the proximal effects referring to the pure sensorial and motor feedback from the executed movements, thus distinguishing the TEC approach from the classical ideomotor accounts (Lotze, 1852; James, 1890). By drawn on an old distinction between the proximal and distal stimulus (Heider, 1926/1959; 1930/1959, Brunswik, 1944), the proximal codes deal with the visual, kinaesthetic or motor information provided by some specific feature-detection receptors, thus it deals with information that is restricted to specific sensory channels. Instead, the distal features rely on the proximal information, and represent the more complex informational attributes of the object that integrates information deriving from multiple sources, including memory (Hommel *et al.*, 2001). Moreover, the feature code is not specific of a particular stimulus or response, but in registering the sensory information it also modulates the activities of the various motor systems, thus representing the interface between the perception and the action systems. Within such a view, the feature codes refer to the distal features of the external events, and represent not only simple object dimensions such as shape, colour or location, but also more complex information about the affordances the object evokes. For sake of clarity, let's consider a person that wants to get some coffe from a cup placed on the desk, where the cup represents the stimulus, and reaching represents the most appropriate action for attaining the intended goal. In order to achieve a successful interaction with the object, some features of the object and the action plan have to match; for instance, the intended travelling distance of the hand have to match the perceived distance between the hand and the cup; similarly, the intended grip should match the perceived size of the cup, and so forth. According to the claim of the TEC, "as the action plan consists in specifying and integrating the codes representing the intended action features, and as these codes are already activated in the course of perceiving the stimulus, there is not much more to be done". In particular, the coding process of the distal features for both the to-be-perceived and the to-be-generated events depends on the continuously evolving interaction between the perceiver and his environment. Thus, some feature codes will be activated by the specific interaction with a specific object. Again, let's consider an example for illustrating how the activation of some perceptual feature codes of the observed event entails the activation of the corresponding action feature codes, thus influencing the motor system activity.

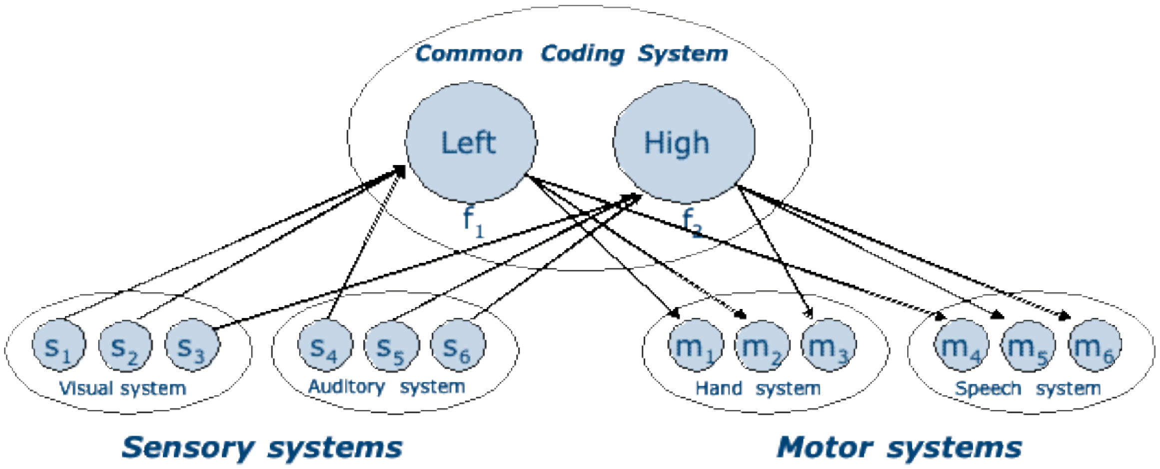

Figure 1: Feature coding based on the proximal coding from the visual and auditory system, and spreading of the activation to the motor systems controlling, for instance, the hand and the speech movements. Sensory and motor information refer to the proximal coding; feature codes in the common coding system refers to the distal coding (adapted from Hommel *et al.*, 2001)

Consider, for instance, a situation in which the cognitive system has to code and represent an external event, say the sound of a violin coming from the left with respect to the perceiver. Assume that the integration of the sensory information coming from the visual and the auditory sensorial system (S1, S2, S3 and S4, S5, S6, respectively; see the left side of the figure 1) converges onto the activation of two abstract feature codes, for instance "left" with reference to the leftness of the visual stimulus (the violin), and "High" with reference to the high pitch of the tone (f1 and f2, in the figure 1). In a very simplified form, one might assume that both the spatial information coded by the auditory system (for instance by S4), and the visual information coded by the visual system (for instance by S1 and S2) contribute to the definition of the spatial location of the tone; likewise, auditory information (for instance coded by S5 and S6), as well as visual cues (say information coming from seeing the violin, for instance coded by S3) could to be used to determine the height of the pitch. Given the aforementioned characteristics of the common coding assumption, some interaction between the perception system and the action system are expected;

thus perceiving an object, as the violin, possessing particulars features (for example, left and high feature codes) will prime those actions that produce the same features. In the example, the activity of the f1 feature code might affect the motor codes of the systems controlling the hand (for instance coded by M1 and M2) for producing a left-directed movement; likewise, the activity of the f2 feature code might influence the motor codes of the speech systems (for instance coded by M5 and M6), and bias the action system to produce a word in a high pitch, or in saying the word "left" speaking aloud.

1.7.3 The behavioural effect of the Event Coding

The heuristic value of the Theory of Event Coding is strengthened by the clear predictions regarding the interaction between the action and the perception systems that can be derived. In particular, the common representational format shared by the to-be-generated and the to-be-perceived events allows some expectations about facilitation and interference effects between overlapping features events. However, before going deeper into this issue, the formation of the event file must be considered. Within the TEC's logic, the event file is built in two phases. The first one consists of the parallel activation of all the event-related feature codes: obviously, the same principle works for both the stimulus processing, wherein all the stimulus-related feature codes are activated, and the action planning, wherein all the feature codes of the intended action are activated. If one or more of the activated perception- or action-feature codes have been used to form a different event code (for instance previously occurred), then the formation of the new event code will be facilitated. Thus, during the first phase, that merely specifies the activation of the perception- or the action-related feature codes, all the activated feature codes will prime the formation of all the to-be-generated or to-be-perceived events characterized by some overlapping feature. Similarly to the formation of the object-file in the Treisman theory, during the second phase a binding process integrates all the activated features in a coherent, final event code. Once the features are associated or synchronized with the event, they are no more available for representing new events, and the facilitation of processes operating on feature-overlapping events turns into interference. Thus, during the second phase all the integrated feature codes will interfere with the formation of any to-be-generated or to-be-perceived event with overlapping features. Several issues have still been left largely unresolved. For instance, one concerns when the feature codes are bounded into the event code, and which sort of binding process underlies the formation of the event code. Also, it is not completely clear whether the perception and the action planning do shares the same binding mechanisms. Furthermore, another issue regards how many feature codes does the to-be-perceived event or the to-be-produced event need to activate in order to get integrated, that is how many feature codes are available for the event processing. Of course, according to the TEC's proponents these issues, together with many others, still need an answer, and further investigation should address them.

According to the selection-for-action approach, the event coding is assumed to depend on the task demands and the current aims of the actor/perceiver: in other words, only the most appropriate feature codes for the successful achieving of the intended goal will be extracted .Thus, the event coding is assumed to be tailored to the situational demands by setting appropriate relative weights for the feature codes. Thus, if a feature code is prominent for a given task, then its activation level will be increased, entailing two specific consequences. First, during the activation phase all the activated feature codes associated with high weights will be more effective in priming all the events with overlapping features; moreover, they will be more promptly integrated into the corresponding event. Second, when during the second phase the feature codes become integrated into the event, all the integrated feature codes associated with high weights will be more strongly represented, thus contributing to a larger extent at interfering with the formation of events that overlap those feature codes. The weighting principle is assumed to be implied in the binding process of both to-be-perceived and to-be-generated events.

Although many questions still need further investigations to be cleared, however the basic principles that the Theory of Event Coding claims are potentially powerful in providing the all empirical data discussed so far with a more comprehensive theoretical ground. In particular, the distal coding approach provides a theoretical framework for the well-known bi-directional interaction between the action and the perception systems, independently of the abstract nature of the stimuli one is attending to or. The common coding approach assumes the bi-directional influence between the stimulus processing and the action planning depending on the functional equivalence between the action and the perception systems inasmuch as they internally represent the distal features of the external events. Overall, the bi-directional mapping effects between motor and perceptual representation ascribed in turn to the visual system distinction in two sub-systems (i.e. Milner & Goodale, 1995) and to the mirror system (i.e. Rizzolatti & Craighero, 2004) are predicted by the TEC, depending on the common coding of motor and perceptual feature in the event file. As one can see, the distal coding level appears to be the conceptual key to cope with the most of the topics raised so far, and more importantly it appear to provide the neurophysiological account in terms of mirror system with a cognitive model whose the theoretical predictions can be experimentally tested. In particular, one might argue the potential vocabulary of actions claimed by Rizzolatti and collegues as a repertoire of well acquired event files that mediate the observation and the performing of the other (to-be-processed or to-be-performed) events. Intriguingly, the representational ground of such event file (or cognitive representation) has been make explicit within the TEC, thus providing some predictions can be tested. Also, within such a framework the action-onto-perception mapping triggered by attending to abstract sequences of stimuli can be accounted for (Schubotz *et al*, 2001). Indeed, as mentioned above, the common representational system entails some patterns of facilitation effects so that the activation of a to-be-perceived event will prime the activation of a to-be-generated events depending on either the overlap extent between the activated feature codes and the weighting degree of the activated features. Thus, attending to a sequence of stimuli where the prominent dimension is the stimulus location will prime the all the to-be-generated events wherein that feature codes is relevant, thereby, a pointing action should be prime than, for instance, a grasping action, due to being the location feature codes a highly weighted code integrated in this event. However, all of these considerations stand on just a theoretical ground. Therefore, the crucial test for the Theory of

Event Coding concerns with investigating, for instance, whether the opposite prediction is tenable, that is whether actively planning an action configures the perceptual system to enhance the processing of stimulus dimensions that are useful for controlling that action, independently of the abstract or action-related nature of the stimuli. Of course, this is tantamount that framing the modulation effect on the perceptual system by the response preparation within a homogeneous and more comprehensive theoretical model. As it will be shown on the next chapter, the present study is aimed to provided the Theory of Event Coding with a crucial test in pursuing two specific objectives: first, to definitively show a motor-visual priming effect on abstract visual stimuli, unaffected by the methodological counfoundings illustrated on the course of the present review. Second, to provide the TEC, appearing to be a fairly comprehensive cognitive paradigm, with an aimed experimental proof, contributing to its testing process.

2. THE COGNITIVE REPRESENTATION OF ACTION AS MEDIATED BY THE EVENT CODING: AN EXPERIMENTAL CONTRIBUTION

2.1 Overview of the studies

The following studies aimed at investigating the cognitive representation of action within the theoretical framework offered by the Theory of Event Coding (Hommel *et al.*, 2001). As it has been showed in the previous section, an increasing body of evidences suggested that the bi-directional modulation effects between action and perception reflect the activation, probably mediated by the mirror system, of stored knowledge about the actions an individual can perform when interacts with the environment around (Rizzolatti *et al.*, 2004; Craighero and Fadiga, 2004). Furthermore, the largely unspecified medium of those internal representations has been discussed, especially with regard to some recently reported findings that still need a more comprehensive explanation. The Theory of Event Coding represents an integrated cognitive model that accounts for most of these findings. More importantly, the theoretical structure of such a framework allows some prediction to be made though, hitherto it still lacks a complete experimental validation.

In this general context, the following experiments aimed at providing an empirical contribution to the validation of the Theory of Event Coding, and pursuing at the same time two goals. On the first place, I aimed at investigating the nature of the cognitive representation of action by assuming, according to the TEC statements, that it consists of a unique entity where both the perception- and the action-related features are strictly integrated. As a consequence of such a perception- and action-related features binding into the event code, bi-directional modulation effects (that is perception-to-action as well as action-to-perception) are predicted by the TEC. However, as it has been broadly discussed in the previous section, until now only a few studies have been aimed at investigating whether and how action modulates perceptual analysis of incoming stimuli. In order to support experimentally the TEC's assumption concerning the content of the cognitive representation, such motor-visual priming effects must be observed. Most importantly, before the Theory of Event Coding can be considered as a comprehensive theoretical model capable of integrating all the above reported effects, a motor-visual priming effect from stimuli that are not the object of the programmed action should be found. For instance, Schubotz and Yves von Cramon showed that attending to particular stimulus dimensions, such as shape and spatial location, of visual abstract stimuli (say, that they were not object of any observed or planned action) apparently configures the motor systems by activating the motor neural circuits that control those actions that would benefit most from stimuli varying on those dimensions (i.e. grasping and reaching, respectively) (Schubotz, Friederici, Yves von Cramon 2000; Schubotz and Yves von Cramon 2001; 2002; 2003). According to the TEC's statements, actively planning a particular action should similarly configure the perceptual system to favour stimuli or dimensions that are useful for controlling that action, independently of the nature of the stimuli, being they action-unrelated or action-related (say, whether the stimuli are the object of the incoming action performing or they are not). Therefore, the first goal of the following studies was to investigate whether setting a particular response-set up biases the processing system in favour of dimensions of the stimulus that are useful to perform that action. In this case, stimulus dimensions that match those action-related dimensions should be easier to process. Importantly, according to the common coding approach of the Theory of Event Coding, such a functional action-onto-perception mapping should be found both when individuals program (and then execute) the action (say, the to-be-generated event), and when individuals observe an image of the action (say, the to-be-perceived event). The second aim I pursued here concerns the development of an experimental paradigm wherein the effect of the action modulations can be directly manipulated. Specifically, an experimental paradigm wherein the action precedes the stimuli processing has been progressively built and refined.

In pursuing these aims, two series of experiments have been performed. The first was aimed at investigating the functional action-onto-perception mapping during the planning and the successively performance of the action. Specifically, I tested whether preparing a grasping or a pointing action was sufficient to bias selectively the perceptual system in favour of size or spatial location stimulus dimension, respectively. According to the TEC suggestions, action planning was taken as a definition of the construct of action. In this series of experiments, the action modulation effect was measured in terms of the priming effect of the action planning on the perceptual analysis.

The second series of experiments dealt instead with the effects of observing an action performed by someone else. Indeed, the bi-directional mapping effects between the motor and the perceptual representations are predicted to depend on the common coding of motor and perceptual features in the event file. Therefore, also the observation and/or perception of the action should affect the stimuli processing by favouring the stimulus dimensions related to the observed actions. Upon demonstrating such a prediction, the Theory of Event Coding would be supported as providing the mapping effects usually attributed to the mirror system with a cognitive explanation, and it would frame the bi-directional modulation effects within a homogeneous cognitive model.

2.2 Planning the action enhances the processing of the action-related stimulus dimensions

EXPERIMENT 1

The next three experiments are pilot studies that have been performed in order to progressively approach the appropriate experimental paradigm finally used for testing the pursued aims. These experiments were mainly aimed at finding out what actions, visual stimuli, and apparatus were more suited to explore the action modulation effects.

In particular, the first experiment pursued a quite general aim by addressing the hypothesis that the action planning affects the processing of abstract action-unrelated stimuli. The procedure of such experiment was designed upon Craighero and colleagues' experiment (Craighero *et al.,* 2002). Differently, in the present experiment the motor-visual effect was expected to be evident also on stimuli that were unrelated to the to-be-acting objects. Indeed, if planning an action biases the perceptual processing in favour of those stimulus dimensions that would be more useful for controlling that action, then planning a grasping action should be expected to enhance the processing of stimuli varying in size. Similarly, planning a pointing action should be expected to enhance the processing of stimuli varying in spatial location. Thus, the effects of two different actions were investigated in order to replicate and generalise the Craighero and colleagues' results.

Hence, in the basic paradigm employed, participants were required to prepare a pointing or a grasping action, and then to perform the planned action after a visual go-signal was detected. Actually, participants prepared two different variants of both the grasping or the pointing action, and then they were presented with the go-signal consisting of an abstract visual stimulus that could possess either congruent, incongruent or neutral action-related features.

According to the main assumptions described above, a motor-visual priming effect should be found on the stimuli possessing congruent action-related features, though they are not the object the action was directed to.

Method

Participants

Seventeen students (12 female) of the University of Leiden (The Netherlands) aged 19 to 24 years (mean age: 20.06) were paid € 6.50 or 2 credit courses to participate in a single session of about 40 minutes. All but two participants were right handed with normal or corrected-to-normal vision, and they were naïve as to the purpose of the experiment.

Apparatus and stimuli

Participants were seated behind a IBM-compatible PC in a small, dimly lit cubicle. All the stimuli were presented on a 17″ monitor (800 x 600 pixel, 32 bit colour), refreshing at 85Hz with a viewing distance of about 60 cm. Stimuli presentation and response recording were controlled through an Experimental Run Time System (ERTS™) version 3.28 (BeriSoft, 1999) script.

A white asterisk (Font Arial, 24 points) was presented at the geometrical centre of the computer screen on a black background, serving as a point of fixation.

The digits "1" and "2" served as visual cues and were displayed at the same location as the fixation point. They suggested the participants the action (precision grip or power grasping; left pointing or right pointing, depending on the block) that they had to plan. In particular, the power grasp action was defined as the object being held as a clamp between the flexed fingers and the palm, counter pressure being applied by the abducted thumb. In contrast, the precision grip action was defined as the object being gripped between the palmar aspect of the terminal phalanx of the index finger and the thumb (e.g., Napier, 1960; Marzke, 1997). Pointing, instead, was defined as the object being touched with only the tip of the index finger.

Six yellow geometrical shapes on a black background served as go-signal stimuli for the action execution. Three of them were employed for the grasping actions. Specifically, a thin rectangle (9.5° x 1.4° of visual angle), a large rectangle (9.5° x 5.7° of visual angle) and a circle (5.7° of visual angle in diameter) served as congruent, incongruent and neutral stimuli, respectively for the precision grip. Moreover, the same shapes were used as incongruent, congruent and neutral stimuli, respectively, for the power grasp. All of the figures were presented at the center of the screen, as the fixation point (see Figure 1.1, top panel).

The three remaining geometrical shapes were employed for the pointing action. Specifically, a 1.9° x 1.9° of visual angle yellow square presented at 11.8° of visual angle at the left or at the right of the fixation point, at eye-level, or at the center of the screen, at 8.5° of visual angle above the fixation point, served as congruent, incongruent and neutral stimuli, respectively, for the left pointing. Moreover, the same shapes served as incongruent, congruent and neutral stimuli, respectively, for the right pointing (see Figure 1.1, bottom panel).

The auditory feedback stimulus for errors consisted of a tone of 880 Hz lasting for 300 ms.

Both the to-be-grasped objects and the to-be-pointed objects were placed on a 30 x 23 cm black board. The board was in front of the participants, from a viewing distance of approximately 40 cm. The object of the grasping action consisted of a white object looking the same as a bottle (see figure 1.2, left panel). In particular, the precision grip required participants to grip the upper part of a the object with the thumb and the index finger of their right hand. Instead, the power grasp required participants to grasp the lower part of the object with their right hand.

The object of the pointing action consisted of two dots (each one being 0,5 mm in diameter) pasted to either the left and the right side of the board (see figure 1.2, right panel). In particular, the left pointing action required participants to point their right index finger-tip towards the left dot, whereas the right pointing required participants to point their right index finger-tip towards the right dot.

The effect from the grasping and pointing action planning was investigated in two different blocks, so that the Experimenter placed the object/objects for the investigated action at the beginning of each block.

Responses to the go-signal occurrence were given by releasing the space bar with the right index finger.

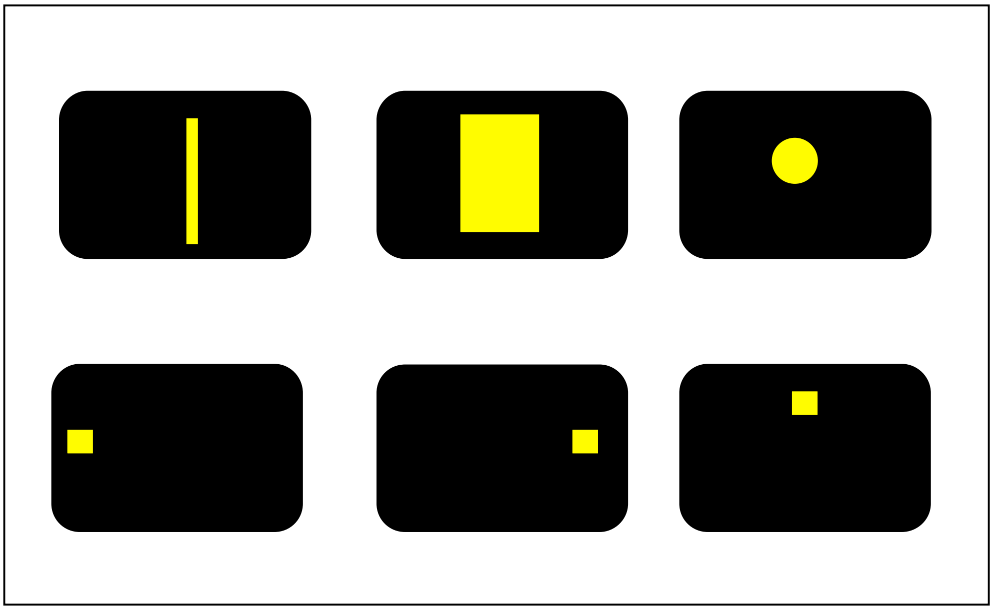

Figure 2.1: Geometrical shapes employed as go-signal stimuli for the action initiation. *Top panel*: Visual stimuli employed as go-signal for the grasping action. *Bottom panel*: Visual stimuli employed as go-signal for the pointing action

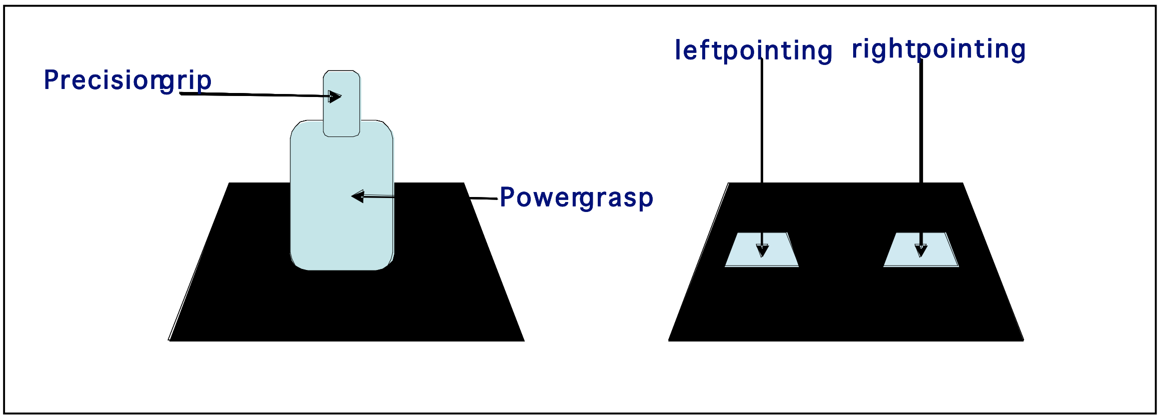

Figure 1.3: Object arrangement in the grasping block (left figure) and in the pointing block (right figure)

Design and Procedure

On each trial, the participants were instructed to plan an action and to execute it as soon as they detected the go-signal. At the beginning of each trial, the fixation point appeared on the screen: when ready, participants pressed the space bar with their right index finger and kept it pressed until the response onset. After the space bar had been pressed, the cue was displayed on the screen for 3 s: it cued the participants for the action (precision grip or power grasp; left or right point, depending on the the block) they had to plan. After a blank whose variable duration ranged from 500 to 1000 ms, the go signal was presented on the screen until a response have been made. Participants were required to release the space bar as soon as they detected the go-signal, and to execute the action on the object according to the cue indication. An experimenter checked for the correctness of the response by classifying as incorrect the responses in which participants performed the wrong action.

Two blocks of 72 trials were run, one for each action (grasping *vs*. pointing). On each block, six conditions were produced by the combination of the within-subjects factors of planned action (precision grip *vs*. power grasp, in one block, left *vs*. right pointing, in the other block) and action-related stimulus (congruent *vs*. incongruent *vs*. neutral).

The cue-action association and the order of the blocks were balanced between subjects.

Mean reaction times (defined as difference between the release of the space bar and the occurrence of the go-signal) computed for every experimental condition were taken as dependent variable for the data analysis. According to the main hypothesis, the action planning has to be found to selectively affect the processing of the incoming visual stimulus. Specifically, the precision grip should enhance the processing of the thin object (congruent stimuli) compared to the large object (the incongruent stimulus) and the neutral stimuli. Likewise, the power grasp should enhance the processing of the large object (congruent stimuli) compared to the thin object (the incongruent stimulus) and the neutral stimuli.

As so far as the pointing is concerned, an analogue congruency effect should be observed, with the preparation of the right pointing that selectively enhances the right stimulus processing (the congruent stimulus) compared to the incongruent stimulus and the neutral stimulus processing; conversely, the preparation of the left pointing selectively should enhance the left stimulus processing (the congruent stimulus) compared to the incongruent stimulus and the neutral stimulus processing.

Results

The Mauchley Sphericity Test performed on the mean reaction times did not show any significant effect, providing evidence that the homoschedasticity assumptions have been met. The mean reaction times were compared with three separate repeated design of Analyses of Variance.

A first two-way ANOVA with Action (grasping *vs*. pointing, collapsed across precision and power grasp, and left and right pointing, respectively) and Congruence (congruent *vs*. incongruent *vs*. neutral) as within-subjects factors failed to show any significant effect.

Following, two separate 2 x 3 ANOVAs for each kind of action (grasping and pointing) were performed. Specifically, a 2 x 3 Action (precision grip *vs*. power grasp) x Congruence (congruent *vs*. incongruent *vs*. neutral) analysis of variance was performed, showing no significant main effects and no significant Action by Congruence interaction. A further 2 x 3 Action (left *vs*. right pointing) x Congruence (congruent *vs*. incongruent *vs*. neutral) analysis of variance was performed, showing a significant effect of the interaction between the factors ($F_{2,32}$=7.09, p<.05). Post-hoc analyses, performed through Duncan Test, revealed a significant congruence effect for only the left-pointing condition (p<.01). Namely, participants were faster at releasing the space bar for executing a left pointing action when the go signal appeared at the left position on the screen (congruent condition) than when the go signal appeared at the right position on the screen (incongruent condition) (388.00 ms vs. 426.29 ms, respectively. See Table 1.1; Figure 1.3). However, no significant difference was observed between congruent *vs*. incongruent stimuli when participants performed a right pointing (407.75 ms *vs*. 393.96 ms, respectively; p=.19; see Table 1.1, Figure 1.3). Mean reaction times to neutral stimuli were intermediate between reaction times to congruent and incongruent stimuli for both left and right pointing, and were not different from any of them (Table 1.1).

No statistical analysis was performed on the error rates due to the participants being very accurate (error rate < 5%).

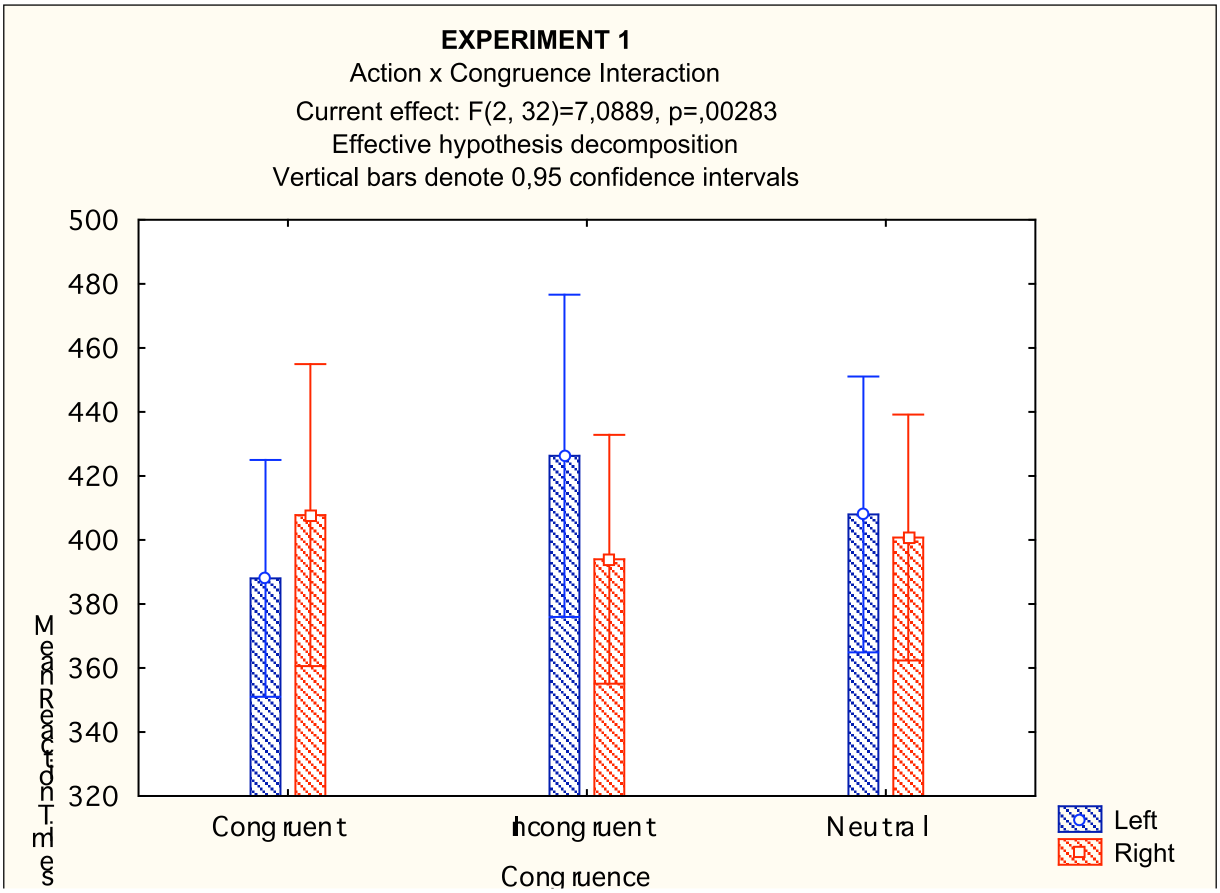

Figure 1.3: (Pointing Reaction Times): Mean Reaction Times as a function of the planned action (left *vs.* right pointing) and the Congruence (Congruent *vs.* Incongruent *vs.* Neutral)

Left Pointing			**Right Pointing**		
Congruent	**Incongruent**	**Neutral**	**Congruent**	**Incongruent**	**Neutral**
387,9964	426,2911	407,9823	407,7542	393,9614	400,7657
71,94784	*97,91153*	*83,80735*	*91,74881*	*75,58939*	*74,70104*

Table 1.1 (Pointing Reaction Times): Mean Reaction Times and Standard Deviation (in italics) as a function of the Planned action (left vs. right pointing) and the Congruence (Congruent vs. Incongruent vs. Neutral)

Discussion

The present experiment was aimed at investigating the hypothesis that planning a grasping or a pointing action makes the processing of action related visual stimuli easier, though such a visual stimuli are unrelated to the to-be-grasped or to-be-pointed objects. The main analysis failed to show the predicted effects. Although such a result contrasts with the main hypothesis, still it raises some important issues. First, it failed to demonstrate an affordance related inverse effect: as it has been discussed, several studies found that the perceptual processing of an object can potentiate the actions that are compatible with the micro-affordances evoked by that object (Tucker and Ellis, 1998; Ellis & Tucker, 2000). The common coding approach predicts the inverse priming effect, wherein planning an action enhances the processing of stimuli whose features are compatible with that action. This was not the case in the present experiment. This might be due to, according to Tucker and Ellis (2004), the presumably activated action knowledge being only broadly tuned, reflecting classes of broadly specified actions. For instance, planning a grasping should activate only prominent information concerning the relevant dimension (i.e. shape *vs*. location), rather than specific parameters concerning the aperture of the grip (say, the difference between precision grip and power grasp), according to the findings of Schubotz and Yves von Cramon (i.e Schubotz *et al*., 2000). On the other hand, this experiment missed the critical comparison between the two broadly defined actions with respect to the different stimulus dimensions (size *vs*. location). This was done in the following experiment. Moreover, as the analysis failed to show significant differences among the congruent and the incongruent stimuli with respect to the neutral stimulus, only neutral stimuli have been used in the following experiments, in order to only manipulate the dimension of the stimulus . However, at least one observed effect of this study deserves further discussion. Indeed, planning a left pointing appeared to enhance the processing of the left stimulus, but the same congruency effect was not found when planning a right pointing. This finding rules out an explanation in terms of mere spatial compatibility effects, as a similar compatibility effect should have been observed when planning a right pointing as well(Simon, 1969). Such an unexpected result suggests that more attention should be paid on the timing characteristics of the formation of the event code. Indeed, the TEC posits that during the second phase the feature binding process occurs, and the integrated features are no longer available to form other event codes. This results in the formation of other event codes with overlapping features being hampered (Hommel *et al.,* 2001). Occupation code effects have been already discussed in literature (Hamilton *et al.,* 2004; Hommel, 2004). Such occupation code effects might account for the absence of a right pointing effect upon processing of right stimuli. On the other hand, it must be noted that, though not significant, a small advantage for the congruent stimulus processing was apparent when participants prepared a right pointing as well. Further investigations, besides the specific aims of the present study, should investigate occupation code effects closer.

EXPERIMENT 2

Findings of the previous experiment failed to show the expected motor-visual priming effect. However, one might take the lack of such an effect as an evidence supporting the Tucker and Ellis claim (2004), according to which the stored knowledge about the action is only broadly tuned. In other words, the content of the action representation that is presumably activated by the action planning would not specify the specific parameters of the motor program useful for the successive execution of the planned action. Rather, the activated representation would be just sketched by defining the relevant feature codes of broad stimulus dimensions, such as size or spatial location. The setup of the previous experiment hindered the critical comparison regarding the different priming effects of the planning action on the graspable (say, stimuli that varied on the size stimulus dimension) and pointable stimuli (say, stimuli that varied on the spatial location stimulus dimension). Specifically, planning a pointing action should selectively enhance the processing of pointable stimuli that vary on the spatial location dimension, compared to graspable stimuli that vary on the size dimension. Conversely, planning a grasping action should selectively enhance the processing of graspable stimuli that vary on the size dimension, compared to pointable stimuli that vary on the spatial location dimension. Such comparison was made in the present experiment by presenting the participants with graspable and pointable stimuli. Moreover, the affordance of the stimuli was manipulated, by presenting stimuli that did not afford any grasping or pointing action. The supposed enhanced processing was expected to be less evident for such stimuli than for the affordable stimuli.

Method

Participants

Fifteen students (11 female) of the University of Leiden (The Netherlands) aged 19 to 26 years were paid € 6.50 or 2 credit courses to participate in a single session of about 40 minutes. All the participants were right handed with normal or corrected-to-normal vision, and they were naïve as to the purpose of the experiment.

Apparatus and stimuli

The stimulus material and the apparatus were the same as in Experiment 1, except for the visual stimuli employed as go-signals. Specifically, a non-sense figure (about 9.5° x 9.5° of visual angle) and a square (1.9° x 21.9° of visual angle), served as affordable stimuli: in particular, they were expected to evoke the graspability and pointability affordance, respectively. Furthermore, a brushed circle (9.5° of visual angle in diameter) and a brushed background served as unaffordable stimuli: in particular, the former was employed as an ungraspable stimulus, whereas the latter was employed as an unpointable stimulus. All of the visual stimuli were yellow on a black background, and were presented at the geometrical centre of the screen except for the pointable stimulus that was presented at the center of the screen on the horizontal axes and at 8.5° of visual angle above the fixation point (see figure 2.1).

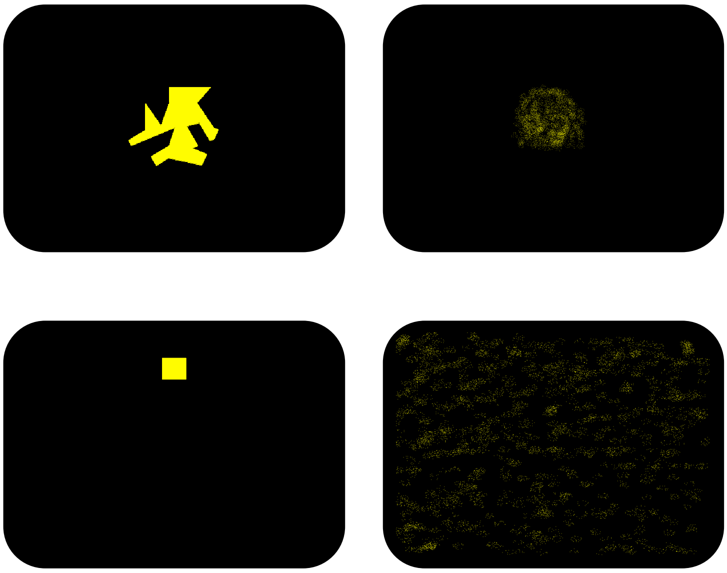

Figure 2.1: the visual stimuli employed in the Experiment 2 varied with respect to the action afforded (grasping vs. pointing) and the affordability (affordable vs. non- affordable)

Design and Procedure

The procedure was largely the same as the Experiment 1, with participants being required to plan a grasping (precision grip *vs.* power grasp) or a pointing action (left *vs.* right pointing) upon cue presentation, and successively to execute the planned action and hence release the spacebar as soon as they detected the go signal. Participants performed four blocks (two blocks for the grasping actions; two blocks for the pointing actions) of 48 trials each, preceded by 48 practice trials. Unlike the previous Experiment 1, participants were presented with all the visual stimuli in each block. Specifically, in the grasping blocks the participants were instructed to prepare a precision grip or a power grasp, while they were presented with either the graspable, ungraspable, pointable or unpointable stimulus. Likewise, in the pointing blocks the participants were instructed to prepare a left or a right pointing, while they were presented with either the graspable, ungraspable, pointable or unpointable stimulus. Main reaction times were analysed by comparing the three within-subjects factors of Planned Action (grasping *vs*. pointing), Afforded Action (grasping *vs*. pointing) and Affordance (affordable *vs*. non-affordable). In particular, reaction times to the affordable stimuli were expected to be faster than to the non-affordable stimuli. Crucially, a significant second-order interaction was expected, with reaction times on the graspable stimuli being faster while participants were planning the grasping action (independently of the grasping variant). Similarly, reaction times on the pointable stimuli were expected to be faster while participants were planning the pointing action (independently of the direction of the pointing action).

Results

The Mauchley Sphericity Test performed on the mean reaction times showed no significant effects, providing evidences that the homoschedasticity assumptions have been met.

A first three-way ANOVA was performed on the mean reaction times with Planned Action (grasping *vs*. pointing), Afforded Action (grasping *vs*. pointing) and Affordance (affordable *vs*. non-affordable) as within-subjects factors. The analysis revealed main effects of both Afforded Action and Affordance ($F_{1,\ 14}$=11,48, p<.01; $F_{1,\ 14}$=11.27, p<.01, respectively), as well as significant interaction effects of Planned Action by Affordance, and Afforded Action by Affordance ($F_{1,14}$=8.48, p<.05; $F_{1,14}$=37.5, p<.001, respectively; see Figure 2.2). In particular, post-hoc analysis revealed that participants were slower at responding to the affordable than the non-affordable stimuli when they had planned a pointing action (352.75 ms *vs*. 335.21 ms, respectively; p<.01); moreover, the processing of the pointable stimulus were slower with respect to the other visual stimuli (p<.01, for all of the conditions; see Table 2.1). No significant effect was found for the second-order interaction.

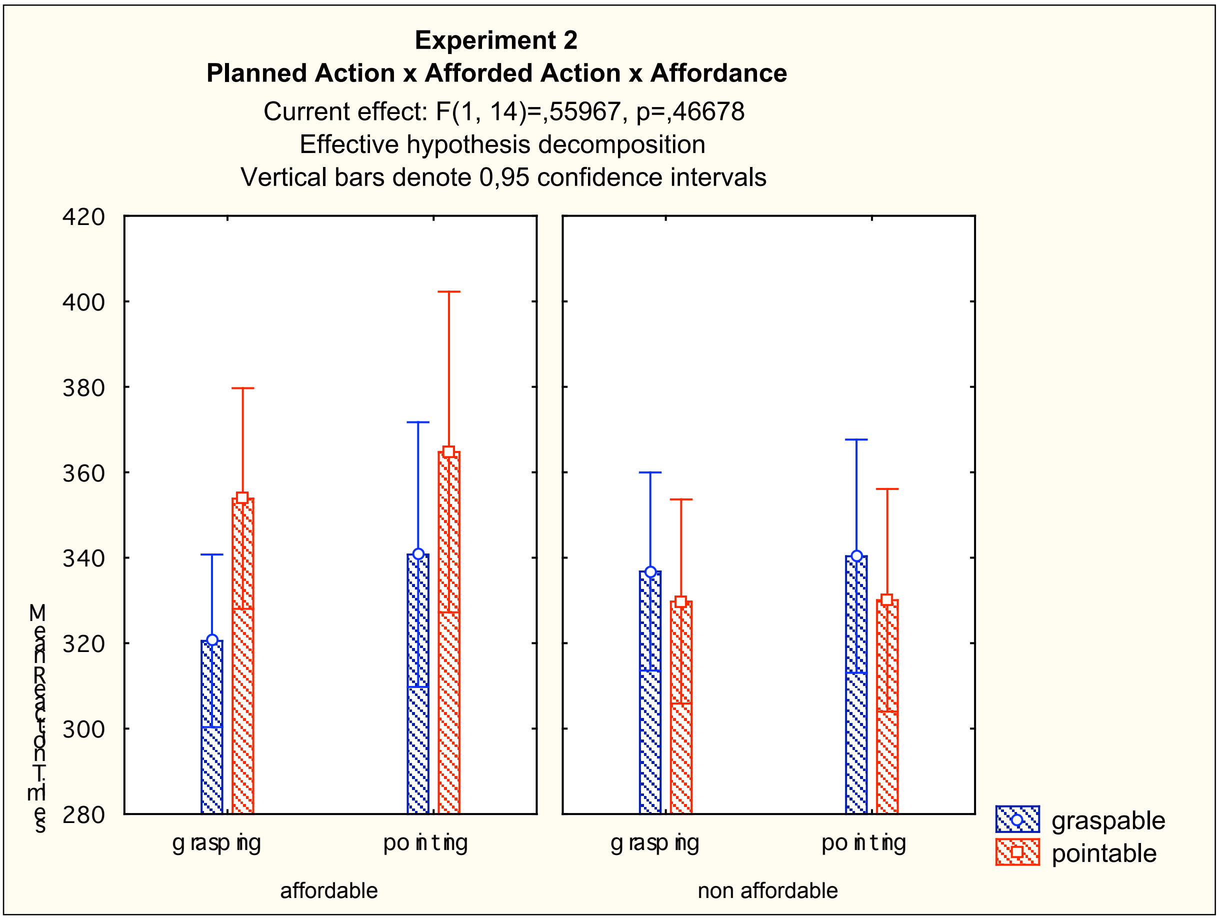

Figura 2.2: Mean Reaction Times as a function of the Planned action (grasping *vs.* pointing), Afforded Action (grasping *vs.* pointing) and Affordance (affordable *vs.* non-affordable)

GRASPING				**POINTING**			
GRASPING		**POINTING**		**GRASPING**		**POINTING**	
Afford.	**Non afford.**	**Afford.**	**Non afford.**	**Afford.**	**Non afford.**	**Afford.**	**Non afford.**
320,5513	336,7925	353,8571	329,7591	340,7432	340,3596	364,7514	330,0634
36,48393	*41,8516*	*46,64949*	*43,12638*	*55,94957*	*49,28183*	*67,75801*	*47,02874*

Table 2.1: Mean Reaction Times and standard deviation (in italics) as a function of the Planned action (grasping *vs*. pointing), Afforded Action (grasping *vs*. pointing) and Affordance (affordable *vs*. non-affordable)

Moreover, the mean reaction times for each kind of action (grasping *vs*. pointing) were compared by two separate ANOVAs. First, an analogue 2 x 2 x 2 repeated measures design was performed with Planned Action (power grasp *vs*. precision grip), Afforded Action (grasping *vs*. pointing) and Affordance (affordable *vs*. non-affordable) as within-subjects factors. The analysis showed a main effect of the Afforded Action, as well as a significant Afforded Action by Affordance interaction ($F_{1,14}$=14.98, p<.01; $F_{1,14}$=32.31, p<.001, respectively). In particular, Duncan testing revealed that participants were faster at responding to the graspable than the ungraspable stimuli (320.39 ms *vs*. 336.72 ms, respectively; p<.05); however, the detection of the pointable stimulus was slower than the other visual stimuli (p<.05). Finally, the 2 (right *vs*. left pointing) x 2 (grasping *vs*. pointing) x 2 (affordable *vs*. non-affordable) ANOVA repeated design with Planned Action, Afforded Action and Affordance as within-subjects factors revealed main effects of Planned Action, Afforded Action and Affordance ($F_{1,14}$=9.28, p<.01; $F_{1,14}$=4.17, p=.06; $F_{1,14}$=15.01, p<.05, respectively), as well as an Afforded Action x Affordance significant interaction ($F_{1,14}$=17.37, p<.001). The post-hoc analysis performed through the Duncan Test showed that participants were faster in starting a right than a left pointing action (M=338.73 vs. 350.31), and again the detection of the pointable stimulus being slower than the detection of the other visual stimuli (p<.01).

No analysis was performed on the error rates due to the participants being very accurate (error rate < 5%).

Discussion

Also this experiment failed to give evidence for the expected motor-visual effects predicted according to the TEC. However, the lack of a significant second order interaction among the three factors was probably due to the difficulty of visual processing being not equated for the different stimuli. Indeed, the processing of the pointable stimulus was impaired, independently of the action the participants were planning. On the other hand, the ANOVA performed on the RTs collected in the grasping blocks showed that the motor-visual priming effect was only evident on the graspable stimulus processing, and that's in with to the main hypothesis. However, also in these blocks participants were slower when processed the pointable stimulus compared to all the other visual stimuli. Likely, the longer reaction times to the pointable stimulus was due to it being the only one that was not displayed at the center of the screen. The different spatial location might require a shift of the spatial attention, thus entailing a cost of processing. To cope with this confounding, the present experiment was replicated with the only exception tha the pointable stimulus was presented at the centre of the screen,. Reaction times from 4 participants were analysed, but the analysis of variance again failed to show any significant effect.

EXPERIMENT 3

Altogether, findings from the Experiment 1 and 2 failed to show the expected motor-visual priming effect on the relevant stimulus dimensions. Notwithstanding this negative result, the experiments still provided useful suggestions for the following experiments. Especially, results of Experiment 1 suggest that the cognitive representation of events might be just sketched in order to bias the perceptual system in favour of the stimulus dimensions whose the action would mostly benefit. The Experiment 3 will try to disambiguate some of the results of the previous Experiment 2. Indeed, that experiment showed a motor-visual priming effect of only the grasping preparation on the graspable stimulus processing. Hence, some modifications were made in order to make the motor-visual priming effect more evident. First, only one variant for each kind of action was investigated. Second, following the experimental setup used by Schubotz and colleagues, participants were required to attend to a sequence of stimuli, instead to a single stimulus, in order to induce them at actively process the dimension of the stimuli. Coherently to the previous Experiment, visual stimuli in the sequences might vary on both the size or the spatial location dimensions. Planning a grasping action was expected to make the stimulus size processing faster compared to the spatial location processing. Conversely, planning a pointing action was expected to make the spatial position processing faster compared to the stimulus size processing.

Method

Participants

Eighteen students (11 female) of the University of Leiden (The Netherlands) aged 19 to 26 years were paid € 6.50 or 2 credit courses to participate in a single session of about 50 minutes. All the participants were right handed with normal or corrected-to-normal vision, and they were naïve as to the purpose of the experiment.

Apparatus and stimuli

The material stimulus and the apparatus matched the previous experiments in all the respects, except that the detecting the go signal was replaced with a visual discrimination task. Moreover, participants were required to plan and to execute only one variant of the pointing and the grasping actions, with the digit that cued for one of them or the other.

A "small" (0.67° of visual angle in diameter) and a "large" (1.24° of visual angle in diameter) yellow circles served as visual stimuli for the "size discrimination task". Both the stimuli were presented successively at the rate of 600 msec, at the center of the screen, 8.5° of visual angle above the fixation point (see Figure 3.1, A).

A yellow circle (0.67° of visual angle in diameter) served as visual stimulus for the "spatial location discrimination task". The stimulus was successively presented at 11.8° of visual angle at the left or at the right of the fixation point, at eye level (see Figure 3.1, B).

The grasping and pointing actions were executed upon a 2 x 2 x 2 cm white cube and a 5 mm in diameter white dot, respectively. The grasping action consisted in picking and lifting the cube with the thumb and the index finger of the right hand. The pointing action consisted in touching the dot with the right index finger-tip. The two objects were placed at the center of two squares plates (10 x 10 cm) horizontally arrayed in front of the participant, with a viewing distance of approximately 40 cm. In particular, two photocells were mounted at two of the corners of the plates in producing a beam of light. The beam of light was interrupted by the graspable objects but not by the pointable objects. By such experimental arrangement, the time of the movement, beside the time of the stimulus processing, was recorded either when participants picked up the object (in the grasping action) and when the participants touched the dot (in the pointing action).

Design and Procedure

On each trial, the participants were instructed to press the space bar upon seeing the fixation point; the digit 1 or 2 occurred for 3 s and cued participants for the action (grasping or pointing) that they had to plan. After 700 ms, the visual discrimination task started. Specifically, the participants were presented with one of two sequences of stimuli. The sequences consisted of the successively displaying of seven yellow circles, and they were designed so that the participants could easily predict both the size or the spatial location of the next circle within the sequence. In particular, the two sequences differed on the basis of the stimulus dimension (size or location) the participants were required to attend to. Thus, one might distinguish among a size varying sequence and a spatial location varying sequence. In turn, the two sequences characterised the two visual discrimination task, where the participants were instructed to find the oddball. Specifically, on the "size discrimination task", the small and the large yellow circles were alternatively presented at the top of the screen at a rate of 600 ms, without temporal gap (see Figure 3.1, A). Instead, on the "spatial location discrimination task", a yellow circle was alternatively presented on the left and on the right with respect to the centre of the screen at a rate of 600 ms without temporal gap (see Figure 3.1, B).

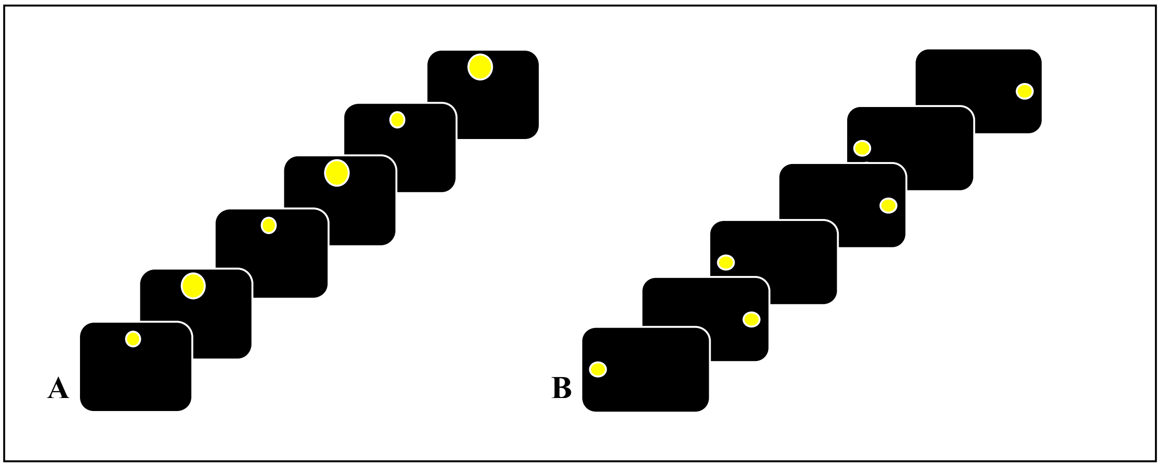

Figure 3.1: The two visual discrimination task the participants were required to attending to. **A:** *Size discrimination task* - Participants were required to discriminate the target that was displayed with the same size of the previous one. **B**: *Spatial location discrimination task* - Participants were required to discriminate the target that was displayed in the same spatial location of the previous one

Each sequence contained seven circles, and in 75 % of all the trials a deviant stimulus was displayed after either the 3rd (25%), the 4th (25%) or the 6th (25%) figure, consisting in the repetition of two circles of the same size ("size discrimination task") or in presentation of a circle in the same location twice ("spatial location discrimination task"). The deviant stimulus was the target stimulus of the visual discrimination task: specifically, participants were instructed to release the space bar as soon as they saw the target stimulus, and to execute the planned action with the same hand.

Participants performed 4 blocks of 32 trials, preceded by 16 practice trials. On two blocks, they performed the "size discrimination task", whereas in the remaining blocks they performed the "spatial location discrimination task". The cue-action association, the presentation order of the blocks and the objects arrangement on the plates were balanced across subjects.

Four conditions were produced by the planned action (grasping *vs*. reaching) and the stimulus dimension (size *vs*. location).

Two dependent variables recorded for each experimental condition were considered: the "releasing time" was defined as time between the go-signal occurring and the spacebar release; the "movement time" was defined as interval from releasing the space bar to either touching the plate (in a pointing action) or lifting the object (in a grasping action).

Results

Mean Releasing RTs Analysis. The mean releasing times recorded for each experimental condition were compared through a 2 x 2 repeated ANOVA with Planned Action (pointing vs. grasping) and Stimulus Dimension (size vs. location) as within-subjects factors. The analysis revealed a main effect of the Stimulus Dimension ($F_{1,17}$=6.57, $p<.05$) due to participants being slower in the size discrimination task than in the spatial location discrimination task (564.93 ms vs. 538.52 ms, respectively). No other significant effects emerged from this analysis.

Mean Movement RTs Analysis. A similar repeated ANOVA was performed on the mean movement RTs, revealing a main effect of the Planned Action ($F_{1,17}$= 35.94, $p<.0001$), with the execution of the pointing action that was slower than the execution of the grasping action (650.3 ms vs. 512.14 ms, respectively), as well as a significant effect of the interaction between the two factors ($F_{1,17}$= 4.52, $p<.05$). In particular, Duncan testing showed that pointing action was slower when participants had processed the spatial location information than when they had processed the stimulus size information (672.02 ms vs. 628.40 ms; $p<.05$), whereas nor the spatial location nor the stimulus size processing gave effects on the grasping action ($p>.05$).

No analysis was performed on the error rates of both the mean releasing and mean movement RTs, due to the participants being very accurate (error rate < 5%).

Discussion

As far as the mean movement reaction times are concerned, the analysis showed that processing the spatial information made the execution of the pointing action slower that the execution of the grasping action. However, as the time for the execution of the grasping and the pointing actions are necessarily different because of the specific on-line adjustment (say, the online adjustment of the grip aperture in the case of grasping action; and the online matching between the pointing action and the target location in the case of the pointing action) of each action type, it turns out that the movement reaction times of both the actions were not comparable. This consideration was also supported by the standard deviations computed for each experimental condition being very large. For this reason, the movement reaction times were no longer considered in the next Experiments.

The main analysis on the releasing reaction times failed again to show the expected interaction between the planned action and the stimulus dimension Also in this case, a methodological confounding potentially hampers the interaction effect being revealed. Indeed, the analysis of variance showed a main effect of the stimulus dimension, with the participants being slower at detecting the go-signal in the sequence where the relevant dimension was the size of the stimuli. Given the setup of the two visual discrimination tasks, one might argue that such impaired processing was due to the change of stimuli spatial location being visually more evident than a change of the size of the stimuli. It is worth to note that the alternation of the spatial position of the stimuli in the sequence implies that the stimulus representing the go-signal was displayed in the same visual hemifield, of the preceding stimulus. Hence, the visual change the participants were required to recognize in order to start the motor response was easier to detect in the spatial location sequence than in the size sequence. Of course, a change of the spatial location in the spatial location discrimination task was the prerequisite for testing the main hypothesis. On the other hand, balancing the discriminability of the two kinds of visual targets appears to be necessary in order to rule out alternative explanations,. Moreover, such a pilot phase aimed at mainly refining the stimulus material for setting up the appropriate experimental paradigm where the potential motor-visual priming effect would exclusively be ascribed to the main hypothesis.

Thus, the next Experiment coped with these methodological confounding by balancing the difficulty of the discriminability of the two sequences.

EXPERIMENT 4

The following experiment was designed in order to cope with the methodological confoundings that probably affected the results of the previous Experiment 3. To this aim, the participants were presented with only one sequence where both the size dimension and the spatial location dimension could vary. Again, according to the main hypothesis, planning the pointing action was expected to make the spatial position processing faster; conversely, planning a grasping action was expected to make the size stimulus dimension processing faster.

Method

Participants

Twelve students of the University of Rome "La Sapienza" (11 female) aged 20 to 26 years were recruited to participate in a single session of about 45 minutes. All the participants were right handed with normal or corrected-to-normal vision, and they were naïve as to the purpose of the experiment.

Apparatus and stimuli

Participants sat at a table (120 x 75) in a dimly lit room, facing a 21" monitor (Silicon Graphics 550, 800 x 600 pixel, 32 bit colour), with a viewing distance of 60 cm.

Stimulus presentation and data acquisition were controlled by a Silicon Graphics Double processor Workstation, interfaced with a 3dLabs Oxygen GVX420 video card.

A white asterisk (Font Arial, 24 points) presented at the geometrical centre of the computer screen served as a point of fixation. The digits "1" and "2" served as visual cues, and were displayed at the same location as the fixation point. They suggested the participants for the action (grasping or pointing) that they had to plan.

A series of seven yellow circles on a black background served as stimuli for the visual discrimination task. On each trial, they were successively displayed at a rate of 600 ms without temporal gaps, along one of the two main diagonal axes of the computer screen (at coordinates (100; 525), (200; 450); (300; 375); (400; 300); (500; 225); (600; 150); (700; 75) and (100; 75); (200; 150); (300; 225); (400; 300); (500; 375); (600; 450); (700; 525) pixels, respectively), starting either from the top or from the bottom of the screen. The size of the circles alternated from "small" (0,67° of visual angle in diameter) to "large" (1,24° of visual angle in diameter), or vice versa (see Figure 4.1).

Responses were given by releasing a micro-switch with the right index finger. The micro switch was mounted on a 10 x 5,5 x 3 cm box placed at the centre with respect to the subject's midline, with a distance of 20 cm from the subject's body and 40 cm from the computer screen.

The grasping and pointing actions were executed upon a 2 x 2 x 2 cm white cube and a 5 mm in diameter white dot, respectively. The grasping action consisted in picking and lifting the cube with the thumb and the index finger of the right hand. The pointing action consisted in touching the dot with the right index finger-tip. Both the objects were arranged on a 30 x 23 cm black board placed in front of the subjects at a viewing distance of approximately 40 cm. The arrangement of the objects on the board was balanced between the subjects.

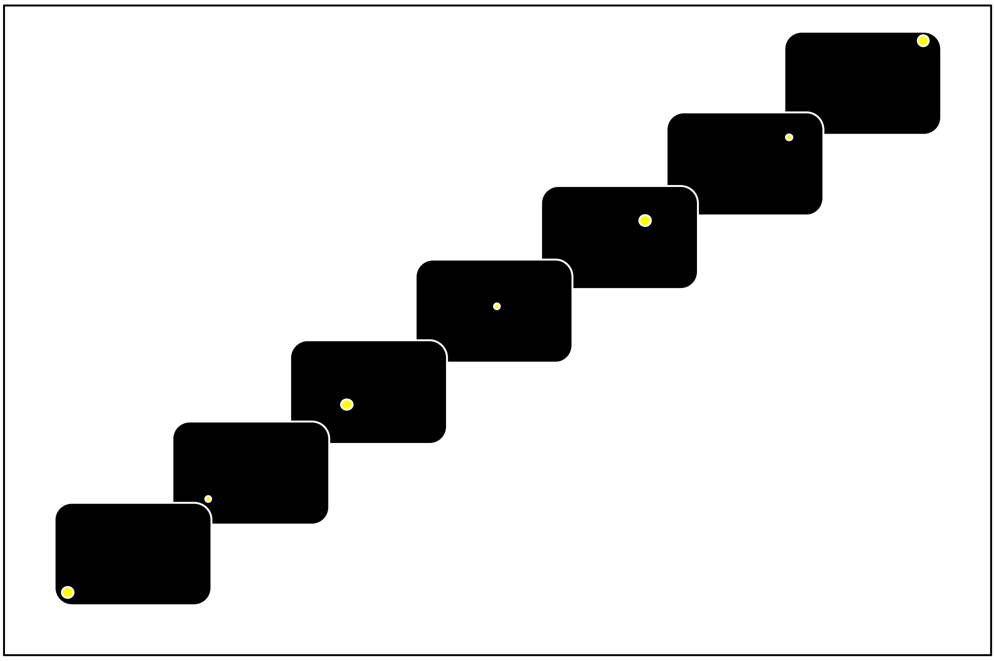

Figura 4.1: Standard sequence employed as visual discrimination task in the Experiment 4. In particular, both the size (twice the same size) or the spatial position (twice the same spatial position) could vary within the sequence, configuring the “size discrimination task” and the “location discrimination task”, respectively

Design and Procedure

On each trial, the participants were instructed to plan the action suggested by the cue, then to perform a visual discrimination task, and finally to perform the planned action on one of the objects placed in front of them.

At the beginning of the trial, the fixation point appeared on the screen: when ready, participants pressed the switch with their right index finger and kept it pressed until the response onset. After the switch had been pressed, the cue was displayed on the screen for 3 s: it cued the participants for the action (grasping or pointing) they had to plan. While keeping the switch depressed, the participants were presented with the visual discrimination task: it consisted of the displaying of a highly predictable sequence containing seven pictures (yellow circles). In each sequence, the circles were presented successively on one of the two main diagonal axes of the screen. In particular, the sequence was predictable with respect to the size and the spatial location of the stimuli: always, the circles were displayed at the same distance one from each other, and by alternating the size (small and large) of the circles (Figure 4.1).

Participants were required to attend to the sequential order of the presented visual stimuli. In fact, in the 75% of all the trials the sequential order of the pictures was randomly violated by presenting a deviant stimulus. Specifically, either the size or the spatial location of the 4th, 5th or 6th stimulus could be repeated, with the circle that was presented twice in a row having the same size (size violation) or the circle that was displayed twice in a row at the same spatial position (location violation). The deviant picture represented the target stimulus for the visual discrimination task.

As participants detected the target stimulus, they were instructed to release the switch and to perform the action on one of the two objects placed in front of them, according to the cue indication. In the remaining 25% of the trials, no violation occurred in the sequence predictability, thus no action had to be performed, and subjects waited for the next trial. An experimenter checked for the correctness of the response by classifying as incorrect the responses in which participants performed the wrong action.

Four conditions were produced by the combination of the within-subjects factor of the planned action (grasping *vs*. reaching) and the within-subjects factor of the stimulus dimension (size *vs*. location). Each condition was replicated 96 times: thus, participants performed 6 blocks of 64 trials (in 3 blocks a violation in size stimulus dimension occurred; in the remaining 3 blocks a violation in the spatial position stimulus dimension occurred) preceded by 20 practice trials. The cue-action association, the object arrangement on the board and the order of the blocks were balanced across subjects.

Mean reaction times (defined as difference between the release of the switch and the occurrence of the target stimulus) computed for every experimental condition were taken as dependent variable for the data analysis.

Results

RTs analysis. Mean reaction times were analyzed through a two-way analysis of variance with the Action (grasping *vs*. pointing) and Stimulus Dimension (size *vs*. location) as within-subjects factors.

The analysis of variance performed on RTs showed a significant effect of the Action ($F_{1,11}$=10.03; p<.01), and a significant interaction between the two factors ($F_{1,11}$=15.01; p<.01; Figure 4.2). In particular, the post-hoc analysis performed through the Duncan Test showed that when participants prepared a grasping action they were faster at detecting the stimuli varying in size than in the detection of the stimuli varying in spatial location (p<.01). Likewise, when participants prepared a pointing action they were faster at detecting the stimuli varying in spatial location than at detecting the stimuli varying in size (p=.09) (Figure 4.2; Table 4.1).

Error analysis. Anticipations (RTs faster than 100ms), missing responses (RTs longer than 1000 ms) and wrong actions were considered as incorrect responses. As participants made few errors (less than 5%) no data analysis was performed on error rates.

Pointing-Size	**Pointing-Location**	**Grasping-Size**	**Grasping-Location**
608,2573	583,011	539,7512	585,7431
110,6665	*99,5553*	*134,6595*	*96,2931*

Table 4.1 Mean reaction times and standard deviations (in italics) as function of the Action and Stimulus Dimension

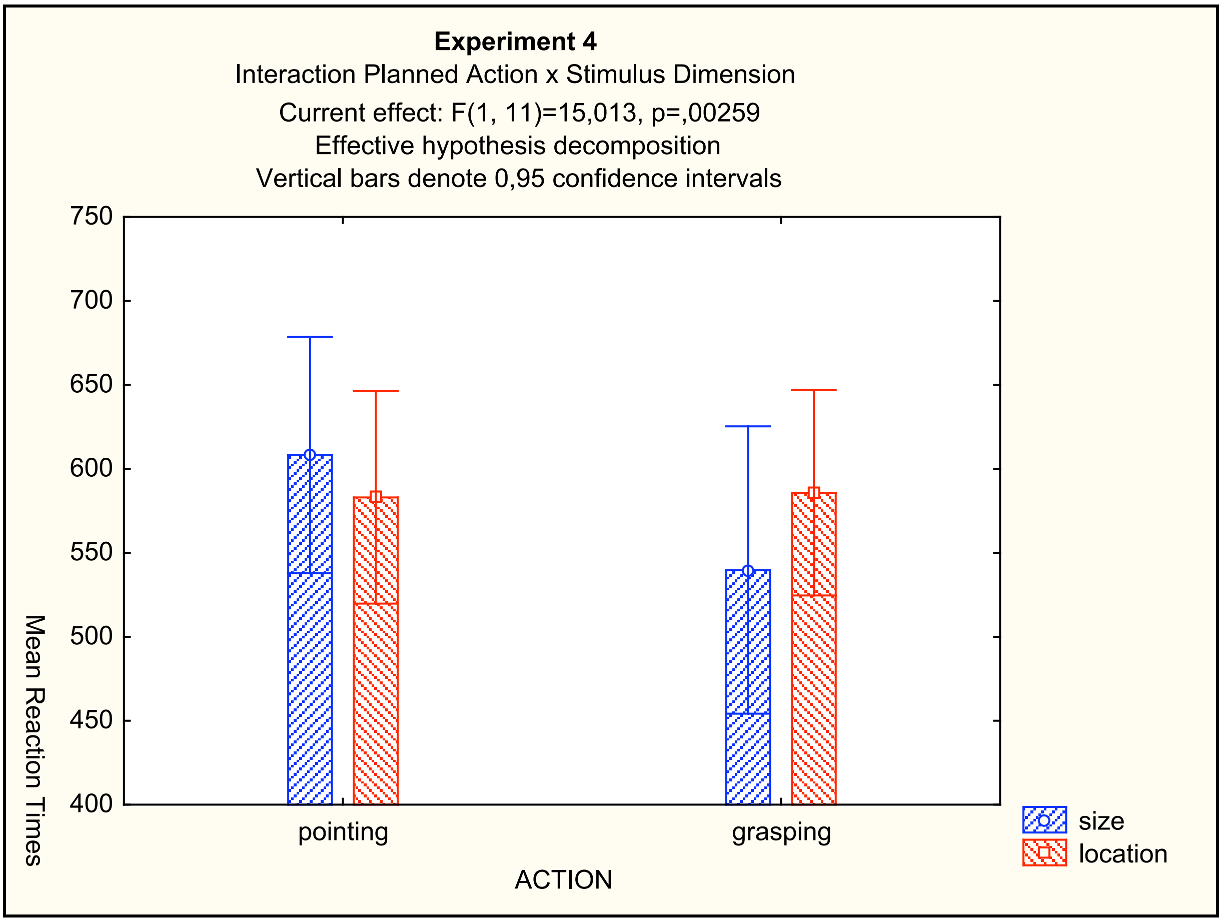

Figure 4.2: Mean reaction times as function of the Action and Stimulus Dimension

Discussion

According to the main hypothesis, the findings of Experiment 4 showed a positive priming of the perceptual analysis by the response preparation: specifically, preparing a grasping action made the processing of the size stimulus dimension faster; instead, preparing a pointing action made the processing of the spatial location stimulus dimension faster. Whilst the observed results appear to support the main hypothesis, however another methodological confounding threats the validity of such interpretation. Indeed, an explanation in terms of action execution priming by the stimulus dimension processing can not be ruled out because of the experimental setup. In other words, monitoring stimuli varying in size or spatial location could bias the motor system by priming the grasping or the pointing action initiation, respectively. The Experiment 5 has been designed to control this potential methodological confounding.

EXPERIMENT 5

Experiment 4 showed a positive priming of perceptual analysis by the response preparation although the experimental setup does not allow to rule out an explanation in terms of visuo-motor priming. In the Experiment 5, such a confounding was addressed by dissociating the perceptual response from the motor response. The general procedure was largely similar as in the Experiment 4 except that participants were required to press a foot-pedal as soon as they detected the deviant stimulus (perceptual response) while they were refraining from both the grasping or pointing movement initiation until the occurrence of an acoustical go-signal (motor response). If the action planning biases the perceptual processing in favour of action-related stimulus dimensions, then a priming effect has to be showed on the perceptual response.

Method

Participants

Nineteen students of the University of Rome "La Sapienza" (14 female) aged 20 to 29 years were recruited to participate in a single session of about 60 minutes. All the participants were right handed with normal or corrected-to-normal vision, and they were naïve as to the purpose of the experiment.

Apparatus and stimuli

The stimulus material and the apparatus were the same as in Experiment 4 except that a 1000 Hz sinus tone of 55 dB represented the go-signal for the releasing of the switch and the following execution of the grasping or pointing planned action.

Also, the response to the target stimulus was given by pressing a pedal-foot placed under the table on the right side of the subject. This device consisted of a push button mounted on a 18 x 12 x 3 box and covered by a 18 x 12 plastic board serving as pedal.

Design and procedure

The procedure was largely the same as in the Experiment 4. After the appearance of the fixation point, participants pressed the switch and planned the pointing or grasping action according to the indication of the cue. While keeping the switch pressed, they attended to the visual discrimination task: they were instructed to press the pedal foot as soon as they detected the target stimulus. At the end of the sequence, an acoustical stimulus was presented for 600 ms, and after that the participants had to release the switch and perform the action, even when no change occurred in the sequence.

Mean foot-pedal reaction times (defined as difference between the time at which the foot pedal was depressed and the time of occurrence of the target stimulus) and mean releasing reaction times (defined as difference between the time at which the micro-switch was released and the time of occurrence of the tone) computed for every experimental condition were taken as dependent variables for the data analysis.

Results

Two analyses of variance were performed on the pedal foot RTs and the releasing RTs, by considering Action (grasping *vs.* pointing) and Stimulus Dimension (size *vs.* location) as within-subjects factors. In the releasing RTs analysis, trials in which no violation occurred were not analysed in order to make the two data analyses comparable.

The analysis performed on the foot-pedal RTs showed a significant interaction between the two factors ($F_{1,18}$=7.02; p<.05). In particular, Duncan testing indicated that planning a pointing action made the spatial information processing faster (p<.05), whereas the planning of a grasping action made the size stimulus processing faster (p<.05) (Figure 5.1; Table 5.1).

The Releasing RTs analysis showed a main effect of the Dimension factor ($F_{1,18}$=6.607; p<.05) with participants being slower in the action initiation when they processed the spatial location than the stimulus size information (605.20 vs. 556.40, respectively; see Table 5.1).

Error analysis. Anticipations (RTs shorter than 100ms; error rate <5%), missing response (RTs longer than 1000 ms; error rate 14.4%) and wrong action (error rate <5%) were considered as errors. A two-way analysis of variance, identical as the pedal RTs analysis, was performed on the missing pedal responses. The results showed a main effect of the Dimension factor ($F_{1,18}$=8.99; p<.001) with participants making more errors in the spatial information processing task.

An analogue analysis was performed on the missing releasing responses (error rate 11%) but the analysis failed to reveal any significant effect.

	Pointing-Size	**Pointing-Location**	**Grasping-Size**	**Grasping-Location**
Pedal RTs	623,5843	612,5407	619,7641	626,2223
	107,0464	*144,2792*	*102,5916*	*149,6922*
Releasing RTs	556,1126	605,4032	556,6964	605,001
	139,8739	*181,6042*	*152,198*	*186,557*

Table 5.1: Mean pedal (top panel), releasing (bottom panel) reaction times and standard deviations (in italics) as function of Action and Stimulus Dimension

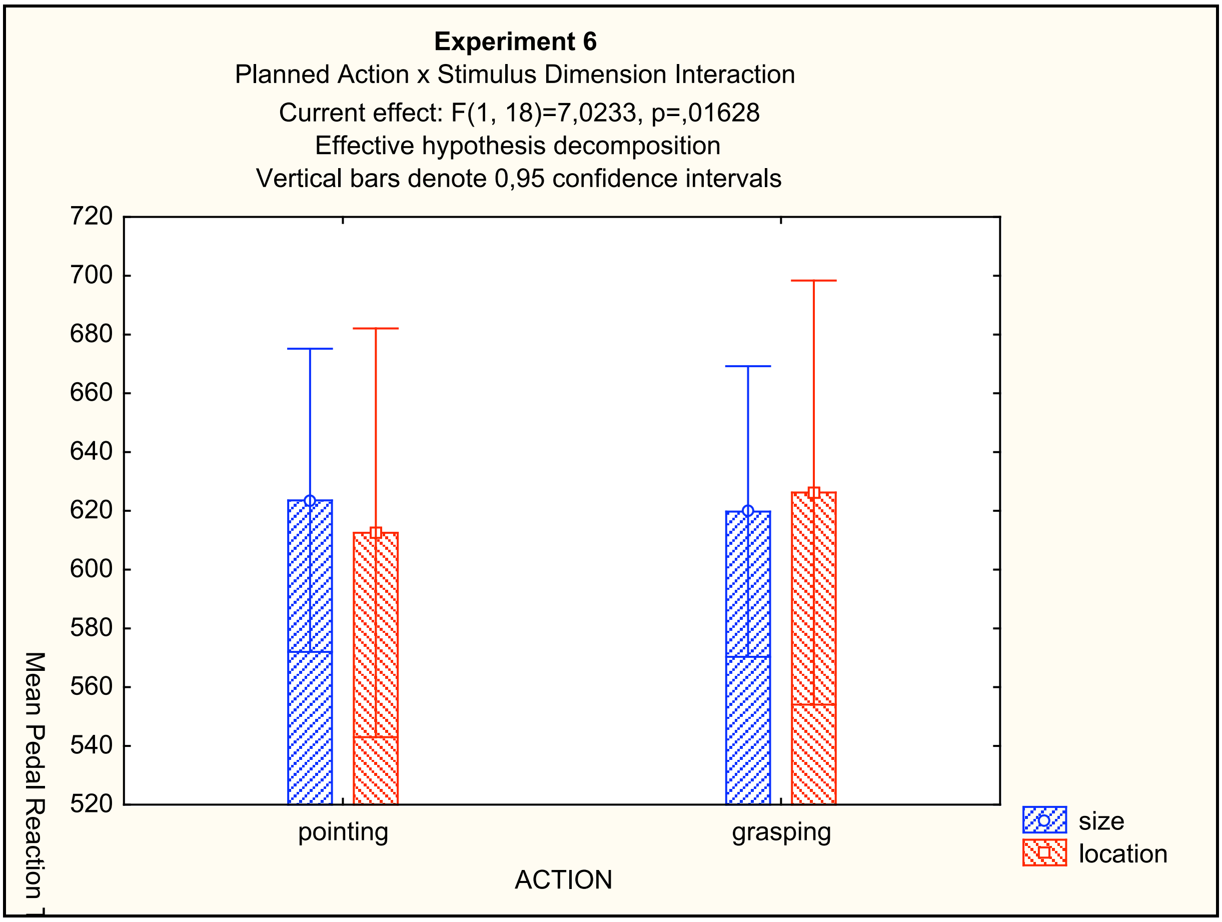

Figure 5.1: Mean foot-pedal reaction times as function of Action and Stimulus Dimension

Discussion

Findings of Experiment 5 showed that the action planning selectively affected the stimulus processing but not the action initiation, as revealed from the pedal and the releasing reaction times analyses.

In particular, participants have been found to be faster in processing the spatial information when they were planning a pointing than when they were planning a grasping action. Conversely, participants were faster in processing the stimulus size when they were planning a grasping action than when they were planning a pointing action. Furthermore, the releasing reaction times analysis showed participants being slower in the action initiation when they processed the spatial information. It is worth to note that participants made more errors in the processing of the spatial information: this result could be attributed to the not-balanced difficulty associated with the two tasks (detection of size or spatial location deviation) that affects the action initiation as well. However, this finding can not account for the selective priming effects observed.

Taken together, findings of Experiment 4 and 5 support the main hypothesis concerning the activation of internal representations mediated by a common coding shared by the action- and perception-related feature codes. In particular, Experiment 4 showed a priming effect of the perceptual processing of action-relevant stimulus dimensions by the response preparation. Specifically, preparing a grasping action made the stimulus size processing faster than the spatial location stimulus processing; conversely, preparing a pointing action made participants being faster in the spatial location stimulus processing than in the size stimulus processing. Most importantly, data from Experiment 5 replicated such a motor-priming effect by ruling out the alternative explanation in terms of visuo-motor priming effect. Some considerations can be drawn from this set of results.

First, the findings of the present study clearly provide empirical evidence for the existence of a motor-visual priming effect. Indeed, in a previous study Craighero and co-workers (1999) showed that preparing a grasping action primed the processing of compatible action-related stimuli even if participants were required to respond to them by using a different effector. In particular, in their Experiment 4, a cue (right or left) informed the participants about the clockwise or counter-clockwise grasping action (respectively) that they had to prepare; while participants were preparing the grasping action, a congruent, incongruent (small or large oriented lines on the computer screen) or neutral (a small or large circle) go-signal was displayed on the screen. Participants were required to respond either by grasping an oriented bar (clockwise or counter-clockwise) if they had seen the small go-signal or by pressing a pedal-foot (or by blinking in the Experiment 5) if they had seen the large go-signal, being the size/go-signal mapping balanced across the participants. Their predictions were consistent with the idea that preparing a grasping action should configure the perceptual system in favour of the size and the bar orientation analysis, independently of the effector used for responding. Results their Experiments 4 and 5 showed that a priming effect of the alternative-effector reaction times was found only for clockwise oriented bars, whereas a priming effect of the grasping reaction times was found independently of the bar orientation (Craighero *et al.,* 1999). It is worth to note, however, that requiring participants to discriminate between the execution of two actions could perhaps interfere with the emergence of the motor-visual priming effect, by making some spatial compatibility effects between the postural arrangement (participants always planned the grasping action with the right hand) and the irrelevant (cue stimulus) or the relevant imperative stimulus (the go-signal) more evident (Kornblum *et al*., 1990; Kornblum & Stevens, 2002).

Such a confounding was not effective in the present experiments because of both the dissociation of the two responses and the not-lateralised nature of the employed imperative stimuli.

Second, the observed findings are consistent with the idea that a mutual interaction between the action and the perceptual systems exist. In particular, a tight link between action planning and perceptual processing of both action-related stimulus dimension or action-compatible stimuli, seems to be underlying the observed action-to-perception modulation effect; at the same time, this finding reveals the representational nature of the action planning. Intriguingly, the results of the present study support the view of a cognitive representation of the event, which goes beyond a mere motor reproduction at neural level of the observed, intended or imagined action (Jeannerod, 2001). Rather, it seems to be in fair agreement with the Tucker and Ellis proposal regarding the cognitive representation of the action as reflecting the activation of broadly tuned action knowledge, built up from a history of past interaction with the objects (Tucker and Ellis, 2004). Again, as discussed above, the representational issue deals with the problem concerning the further specification of the mechanisms subserving the encoding of the perceptual and motor codes in the internally integrated event file. The crucial point for understanding the functional role of the cognitive representations consists in defining their nature: the common coding approach and the theoretical systematization formulated by the Theory of Event Coding appear to be a good starting point for such a specification

By summarizing this first experimental section, the present data empirically support the Theory of Event Coding as a comprehensive theoretical framework that accounts for the action and perception relationships, although the suggested interpretations only holds to the limited extent of the action planning. The followings experiment were aimed at investigating whether the predictions coming from the common coding approach also hold when the perception of an event, say the observation of an action, is involved.

2.3 Observing the action enhances the processing of the action-related stimulus dimensions

EXPERIMENT 6

The following series of studies addressed the main assumption of the Theory of Event Coding concerning the existence of a shared representational medium between action and perception distal feature codes, by investigating whether the same action-onto-perception functional matching observed in the action planning also works during the mere observation of an action. Specifically, a motor-visual priming effect should be evident on the stimulus dimensions that are mostly appropriate to the observed action: so, observing a grasping action was expected to make the processing of the size stimulus dimension faster. Conversely, observing a pointing action was expected to make spatial location processing faster.

As the present first experiment within such a series was performed during the same period as in the Experiment 3, the visual discrimination tasks the participants were required to perform were identical as in that experiment (see Experiment 3, Figure 3.1).

Method

Participants

Fourteen students (9 female) of the University of Leiden (The Netherlands) aged 19 to 26 years were paid € 6.50 or 2 credit courses to participate in a single session of about 40 minutes. All the participants were right handed with normal or corrected-to-normal vision, and they were naïve as to the purpose of the experiment.

Apparatus and stimuli

Participants were seated behind a IBM-compatible PC in a small, dimly lit cubicle. All the visual stimuli were presented on a 17” monitor (800 x 600 pixel, 32 bit colour), refreshing at 85Hz with a viewing distance of about 60 cm. Stimuli presentation and response recording were controlled through an Experimental Run Time System (ERTS™) version 3.28 (BeriSoft, 1999) script. [sposterei la specificazione del software dopo la descrizione del PC]

A white asterisk (Font Arial, 24 points) was presented at the geometrical centre of the computer screen on a black background, serving as a point of fixation.

Six colour pictures of a right human hand, captured through a digital camera, served as visual stimuli, preceding the visual discrimination task. All the pictures were edited on a black background with a 512 x 384 pixel, 8-bit colour resolution. Specifically, each picture reproduced either two grasping, pointing and neutral action variants, each photographed with a single leftward orientation (see Figure 6.1).

Reaction times were acquired by subjects being pressing a standard pedal foot interfaced with a TTL circuit.

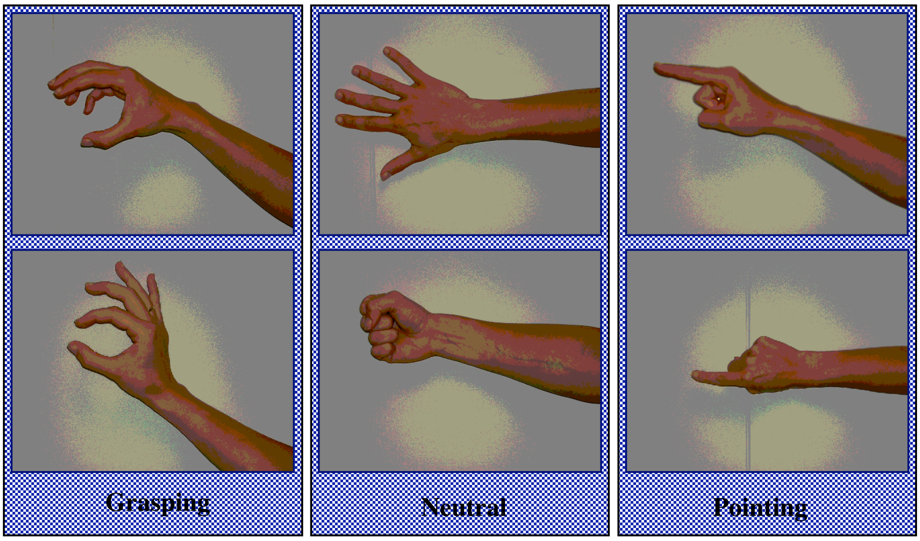

Figure 6.1: The pictures reproducing the action variants of the grasping, neutral and pointing conditions, respectively.

Design and procedure

Each trial started with the occurrence of a fixation point for 2 s. Then, participants were presented with a picture reproducing one of the pictures of a hand. Each picture was displayed for 3 s, and was aimed at priming the cognitive representation of either a grasping, or a pointing, or a neutral action (say, neither grasping or pointing): in particular, two variants could be proposed for each hand configuration: the two variants for the grasping action consisted of pictured representation of the actor hand while was performing a precision grip or a power grasp; the two variants for the pointing action consisted of pictured representation of the actor arm whose the right fore index was pointing towards something: in particular the arm of the actor was captured in two different postures; finally, the two action variants within the neutral condition consisted of the actor arm showing a close hand (forming a fist), or the actor arm showing the open hand (see Figure 6.1). After 700 ms, the participants were presented with the same visual discrimination task used in Experiment 3. Unlike the Experiment 3, however, either the size or the spatial location discrimination task were administered within the same block of trials, in order to prevent any alternative account for the expected results in terms of cognitive strategies adopted by the subjects. The participants were told to press the foot pedal as soon as they detected the target stimulus.

Six conditions were formed by the combination of the within-subjects factor of the observed action (grasping *vs*. pointing *vs*. neutral) and the within-subjects factor of the stimulus dimension (size *vs*. location). The participants performed 8 blocks of 48 trials preceded by 12 warming up trials.

Mean reaction times (defined as difference between the time at which the foot pedal was depressed and the time of occurrence of the target stimulus) computed for every experimental condition were taken as dependent variable for the data analysis.

Results

The Mauchley Sphericity Test performed on the mean reaction times did not show significant effects, providing evidences that the homoschedasticity assumptions have been met.

Mean reaction times were compared through a two-way repeated ANOVA with Observed Action (pointing *vs*. grasping *vs*. neutral) and Stimulus Dimension (size *vs*. location) as within-subjects factors. Results only showed a main effect of Stimulus Dimension ($F_{1,13}=23.92$, $p<.001$), with participants being slower when processed the stimulus size compared to when they processed the spatial location (688.73 ms *vs*. 673.03 ms, respectively), whereas no interaction effect was revealed ($p>.5$) (Figure 6.2; Table 6.1).

No analysis was performed on the error rates, due to the participants being very accurate (error rate < 5%).

POINTING		**GRASPING**		**NEUTRAL**	
location	**size**	**location**	**size**	**location**	**size**

674,4306	685,2017	680,5119	695,0581	664,1347	685,9236
62,83706	*67,46506*	*62,52291*	*65,17637*	*69,09282*	*57,45124*

Table 6.1: Mean reaction times and standard deviation (in italics) as function of the Observed Action (pointing *vs.* grasping *vs.* neutral) and the Stimulus Dimension (spatial location *vs.* size)

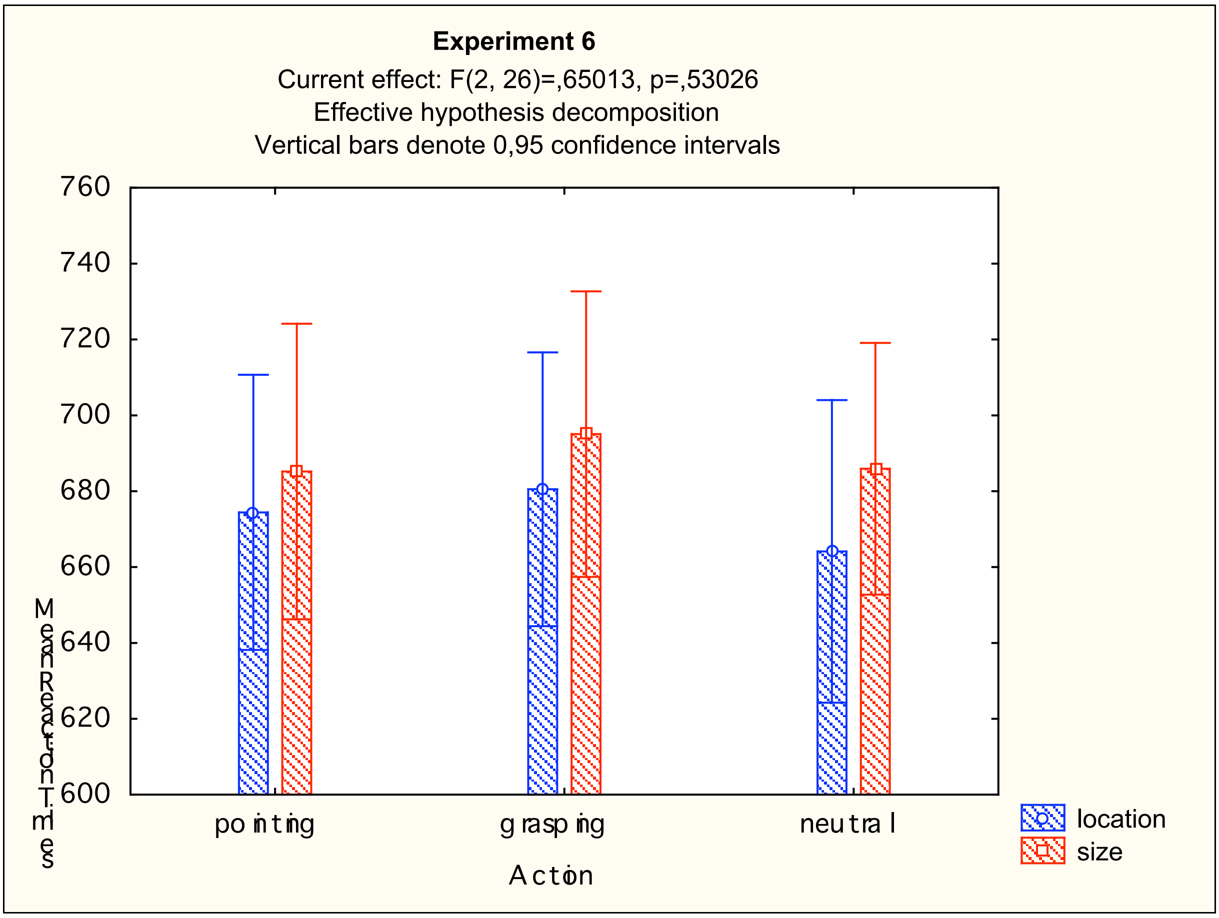

Figure 6.2: Mean reaction times and as function of the Observed Action (pointing *vs.* grasping *vs.* neutral) and the Stimulus Dimension (spatial location *vs.* size)

Discussion

Results of the present experiment failed to show the expected interaction effect between the observed action and the stimuli dimensions. However, at least one result appears to be quite interesting. Indeed, a main effect of the Stimulus Dimension factor was revealed, showing an impairment of the performance when a discrimination of the stimulus size was required. A similar result was shown by the analysis on reaction times in the visual discrimination task in the Experiment 3. Altogether, these findings support the alternative interpretation in terms of methodological confounding that was advanced in the discussion of Experiment 3. Since both the experiments were performed during the same period, the similarity of the results stimulated the design of a different task where either the size and the spatial location visual discrimination were equated. As it was already discussed, a unique sequence of visual stimuli was created wherein both the size or the spatial location stimulus dimension could vary. As with the Experiment 3, the present experiment was replicated by replacing the old visual discrimination task with the new one.

EXPERIMENT 7

In the present experiment the visual discrimination task used in the previous Experiment 6 was modified, by creating only one sequence where, in turn, both the size stimulus dimension and the spatial location dimension could vary. Thus, participants were instructed to attend to both the stimulus dimensions within the presented sequence, as a change in one of them could occur. Again, according to the main hypothesis, observing a hand making a pointing action was expected to make the spatial position processing faster; conversely, observing a hand making a grasping action was expected to make the size stimulus dimension processing faster.

Method

Participants

Thirteen students of the University of Rome "La Sapienza" (10 female) aged 20 to 29 years were recruited to participate in a single session of about 50 minutes. All the participants were right handed with normal or corrected-to-normal vision, and they were naïve as to the purpose of the experiment.

Apparatus and stimuli

Participants sat at a table (120 x 75) in a dimly lit room, facing a 21" monitor (Silicon Graphics 550, 800 x 600 pixel, 32 bit colour), with a viewing distance of 60 cm.

Stimulus presentation and data acquisition were controlled by a Silicon Graphics Double processor Workstation, interfaced with a 3dLabs Oxygen GVX420 video card.

E-Prime software (Psychology Software Tools Inc.) was used for the stimulus presentation and data acquisition.

Visual stimuli aimed at inducing the cognitive representation of the action by their observation (action inducing pictures) consisted of the same digitalized pictures used in the Experiment 6.

A series of seven yellow circles on a black background served as stimuli for the visual discrimination task (cfn. Experiment 4). On each trial, they were successively displayed at a rate of 600 ms without temporal gaps, along one of the two main diagonal axes of the computer screen (at coordinates (100; 525), (200; 450); (300; 375); (400; 300); (500; 225); (600; 150); (700; 75) and (100; 75); (200; 150); (300; 225); (400; 300); (500; 375); (600; 450); (700; 525) pixels, respectively), starting either from the top or from the bottom of the screen. The size of the circles alternated from "small" (0,67° of visual angle in diameter) to "large" (1,24° of visual angle in diameter), or vice versa (see Figure 4.1).

The response to the target stimulus was given by pressing a pedal-foot placed under the table on the right side of the subject. This device consisted of a push button mounted on a 18 x 12 x 3 box and covered by a 18 x 12 plastic board serving as pedal.

Design and procedure

The procedure was largely the same as in the Experiment 6 except that a single sequence embedded both the size and location discrimination tasks (cfn. Experiment 4). After a brief training, the participants performed 8 blocks of 48 trials preceded by 8 warming up trials.

Mean reaction times (defined as difference between the time at which the foot pedal was depressed and the time of occurrence of the target stimulus) computed for every experimental condition were taken as dependent variable for the data analysis.

Results

The Mauchley Sphericity Test performed on the mean reaction times showed not significant effects, providing evidences that the homoschedasticity assumptions have been met.

Mean reaction times were compared through a 3 x 2 repeated ANOVA with Observed Action (pointing *vs*. grasping *vs*. neutral) and Stimulus Dimension (size *vs*. location) as within-subjects factors. The analysis failed to reveal any significant effect, though a main effect of the Observed Action approached the statistical significance ($F_{2,24}$=3.06; p=.07). In particular, the pointing action observation looked to make the visual discrimination task slower compared to both the grasping and the neutral action observation (Figure 7.1; Table 7.1).

GRASPING		**POINTING**		**NEUTRAL**	
size	**location**	**size**	**location**	**size**	**location**
646,1023	641,6513	657,2862	663,1298	646,8382	653,3008
98,1637	*86,7282*	*103,5355*	*86,1716*	*90,6558*	*67,4831*

Table 7.1: Mean reaction times and standard deviation (in italics) as function of the Observed Action (pointing *vs*. grasping *vs*. neutral) and the Stimulus Dimension (spatial location *vs*. size)

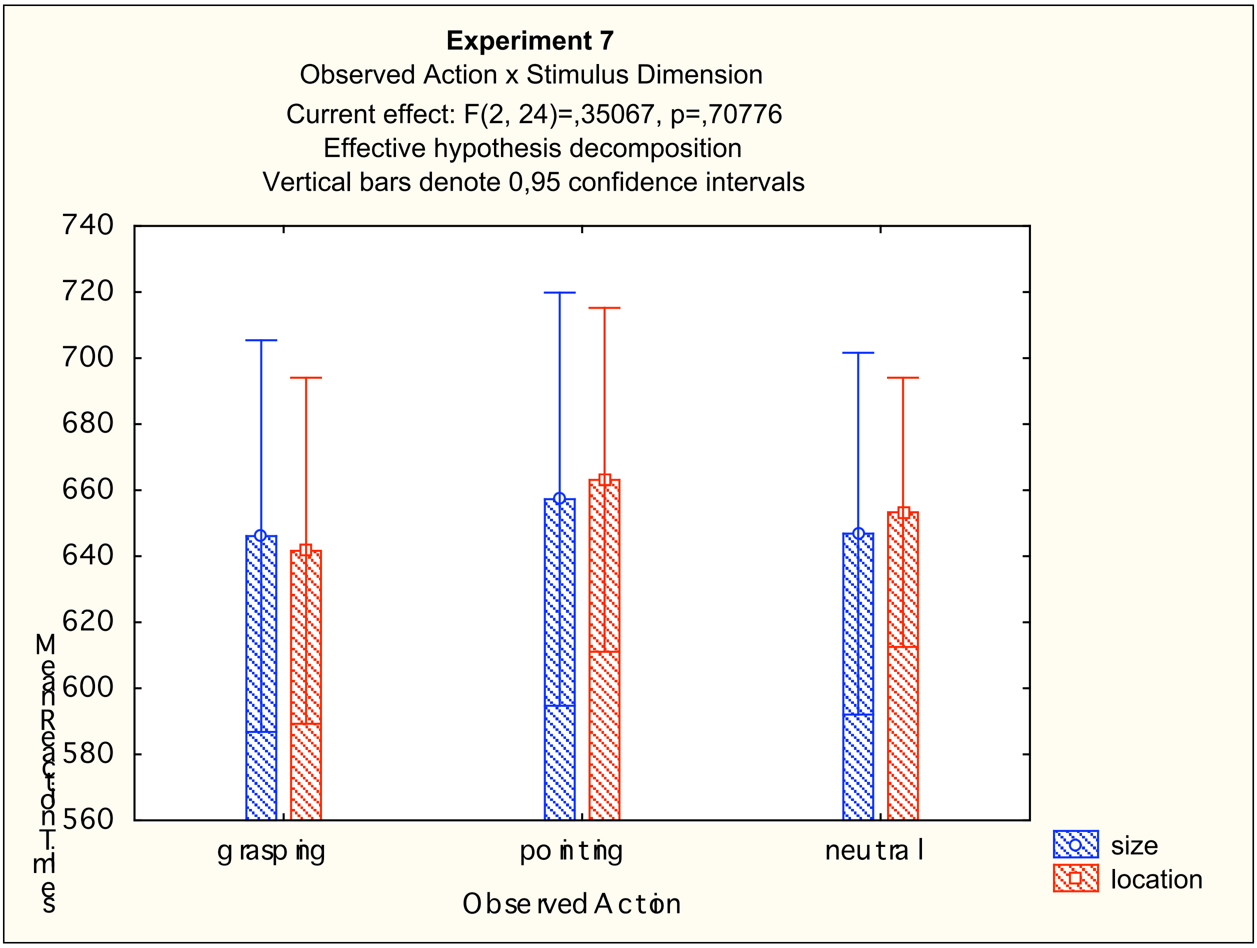

Figure 7.1: Mean reaction times and as function of the Observed Action (pointing *vs*. grasping *vs*. neutral) and the Stimulus Dimension (spatial location *vs*. size)

Discussion

Although the visual discrimination task was modified in order to cope with the methodological confoundings that potentially accounted for the results of the previous Experiment 6, however no significant effect of the interaction between Observed Action and Stimulus Dimension still emerged. Such a result appear to be contrasting with the significant interaction observed when participants had to actively plan the action. The absence of a significant interaction in the present experiment could be obviously due to the action observation being unable at activating the corresponding cognitive representation of the event. Another interpretation concerns with the cognitive representation being activated by the action inducing pictures, but such activation could be less effective than the cognitive representation activated by the action planning. The latter hypothesis appear to likely fit the findings, as a great number of studies empirically discussed the activation of a cognitive representation by the action observation (Craighero *et al.,* 2002; Paccalin & Jeannerod, 2000). More importantly, such a result would contrast with the hypothesis of a common coding for both the action and the perception, according to which both the event perception and the event generation should prime processing of stimuli dimensions. However, it is worth to note that Vogt, Taylor, Hopkins (2003) described an advantage in initiating the grasping action when participants were presented with grasping hand pictures that matched the final posture of both the observer's own hands compared to the perspective of another person. Thus, it may be hypothesized that the perspective could represent a variable able to influence the strength of the cognitive representation activation.

Moreover, one might wonder whether the employed visual stimuli were efficient in activating the cognitive representation of the observed action. Indeed, an almost significant main effect of the Observed Action (p=.07) was found in the present experiment. Such a finding could suggest that the visual stimuli used in the present experiment were not entirely comparable. Actually, at post-experiment interviews some participants referred to have assigned a semantic meaning to the hand pictures, for instance assuming that they represent some standard sign instead of a hand performing an action. In order to cope with this possible confounding, in the next experiment different action inducing pictures were used.

EXPERIMENT 8

The Experiment 8 was designed to cope with the methodological confounding emerged from the data analysis of the previous Experiment 7. In particular, new action inducing pictures were created for enhancing their strength in priming the cognitive representation of the correspondent action. To this aim, an object was introduced to induce the representation of a real interaction between the actor and the object. Moreover, the experiment investigated the extent to which the observer perspective affects the priming of the correspondent action.

Method

Participants

Twenty-one students of the University of Rome "La Sapienza" (14 female) aged 20 to 29 years were recruited to participate in a single session of about 40 minutes. All the participants were right handed with normal or corrected-to-normal vision, and they were naïve as to the purpose of the experiment.

Apparatus and stimuli

The apparatus was largely analogue as in Experiment 7, except for the presented pictures. Specifically, pictures of hands that matched either "own" or "other" perspective were captured by a digital camera, and presented on a 21" monitor (Silicon Graphics 550, 800 x 600 pixel, 32 bit colour) to appear in real size. In particular, the image of a hand that was grasping a white cube (10 x 10 x 10 cm) served as grasping inducing stimulus; instead, the image of a hand that was pointing to a white dot served as pointing inducing stimulus; the hands were photographed in both the "own" or "other" perspectives, resulting in four action pictures (see Figure 8.1).

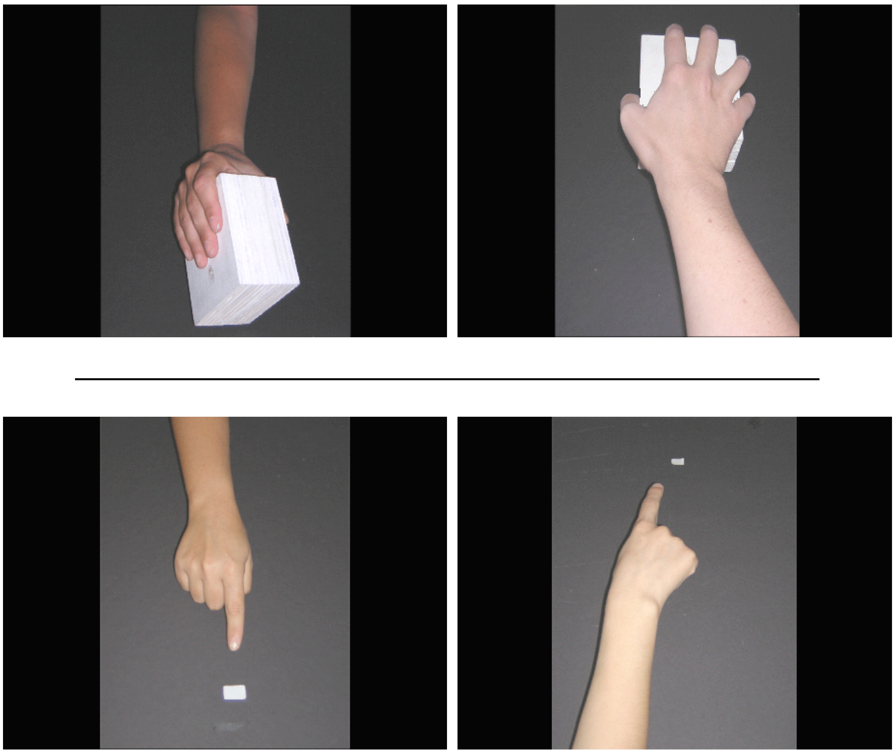

Figure 8.1: Action inducing picture employed in the Experiment 8: the top panel illustrates the grasping inducing pictures in the other (on the left) and in the own (on the right) perspective. The bottom panel illustrates the pointing inducing pictures in the other (on the left) and in the own (on the right) perspective

Design and procedure

The procedure was identical as in the previous Experiment 7. After a brief training, the participants performed 8 blocks of 48 trials preceded by 8 warm trials.

Mean reaction times (defined as difference between the time at which the foot pedal was depressed and the time of occurrence of the target stimulus) computed for every experimental condition were taken as dependent variable for the data analysis.

Results

Mean reaction times compared for each experimental condition were analysed through a 2 x 2 x 2 repeated ANOVA with Perspective (own *vs*. other), Observed Action (pointing *vs*. grasping) and Stimulus Dimension (size *vs*. location) as within-subjects factors. The analysis revealed an approaching statistical significance Perspective x Observed Action interaction ($F_{1,20}$=3.13; p=.09). More importantly a Perspective x Observed Action x Stimulus Dimension interaction effect was revealed, though it only approach the statistical significance ($F_{1,20}$=3.006; p=.098; Figure 8.2). In particular, according to the main hypothesis observing a grasping action made the size stimulus processing faster then the spatial location stimulus processing (M=624.86 vs. 637.76; see Table 8.1); conversely, observing a pointing action made the spatial location stimulus processing faster than the size stimulus dimension (M=618.44 msec *vs*. 636.61 msec; see Table 8.1). Although these differences did not reach the statistical significance as revealed by the post hoc analysis performed through the Duncan test, however, the motor-visual priming effect was only evident when participants observed action pictures in the own perspective.

No analysis was performed on the error rates, due to the participants being very accurate (error rate < 5%).

OWN PERSPECTIVE				**OTHER PERSPECTIVE**			
GRASPING		**POINTING**		**GRASPING**		**POINTING**	
size	**location**	**size**	**location**	**size**	**location**	**size**	**location**
624,8639	637,7622	636,6098	618,4429	627,1474	610,1561	637,2437	619,7669
77,9219	*92,5381*	*81,1686*	*100,9832*	*85,0964*	*92,5019*	*78,0049*	*101,3988*

Table 8.1: Mean reaction times and standard deviation (in italics) as function of the Perspective (Own *vs*. Other), Observed Action (pointing *vs*. grasping) and the Stimulus Dimension (spatial location *vs*. size)

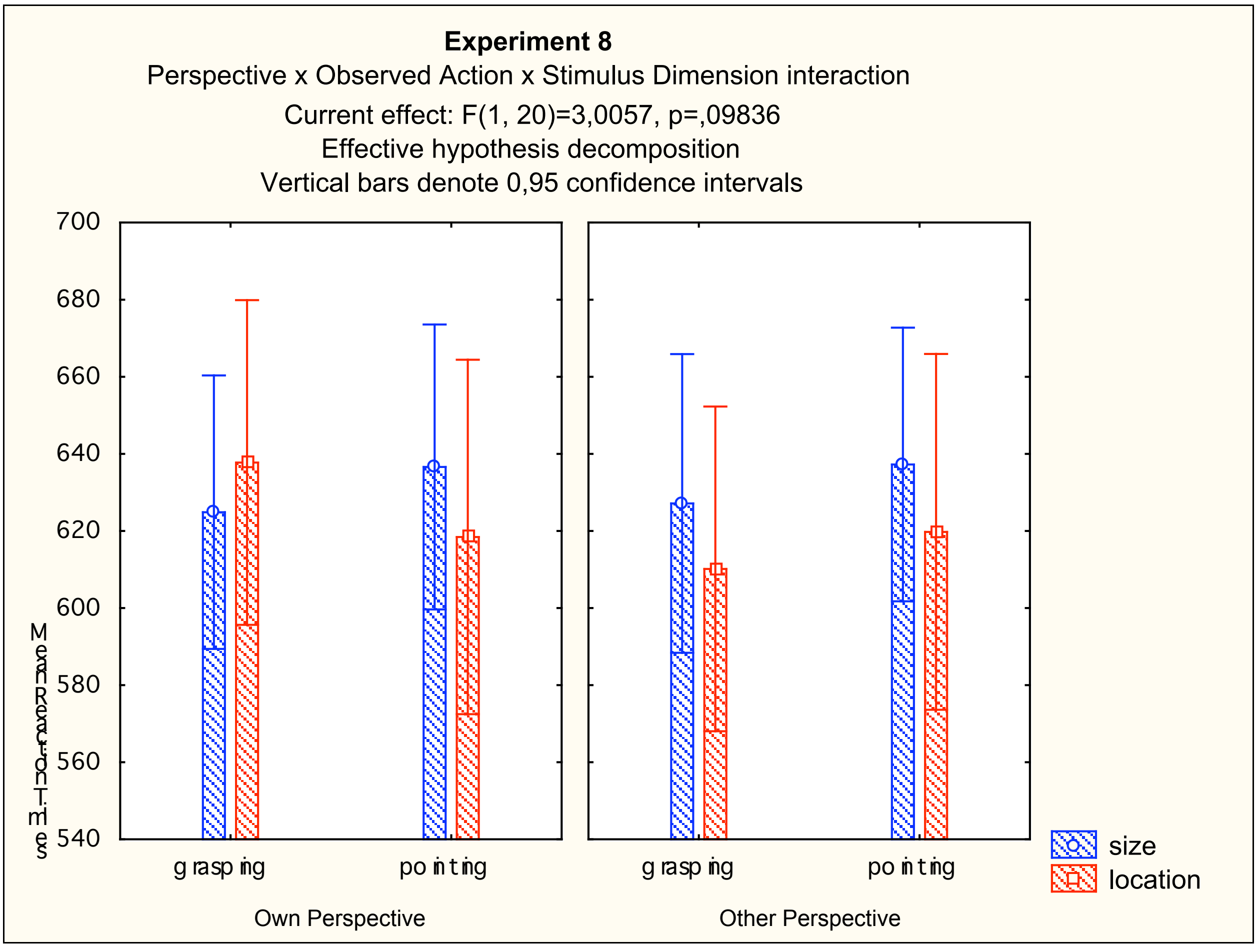

Figure 8.2: Mean reaction times and as function of the Perspective (Own *vs*. Other), Observed Action (pointing *vs*. grasping) and the Stimulus Dimension (spatial location *vs*. size)

Discussion

As far as the action observation is concerned, findings from this Experiment, though only approaching the statistical significance, strongly suggest a motor-visual priming effect of the action inducing pictures on the processing of the stimulus dimension that would be mostly suited for those actions. More importantly, the selective enhanced processing of the stimulus dimensions by the action inducing pictures was evident when the participants attended to action pictures that matched the end posture of the observer's own hand, but not when they attended to action pictures showing the hand from the perspective of another person (Vogt, Taylor, Hopkins, 2003). The influence of the perspective on the induction of the correspondent action activation could account for the failure in revealing the motor-visual priming effect in the previous experiments. Indeed, the old pictures never reproduced the hand configuration from the perspective of the participants. Since the observer perspective plays a crucial role in determining the modulation of the action representation on the perceptual processing, one might infer further specification about the content of the cognitive representation itself. So far, findings of the previous experiments support the idea that the action representation is a broadly tuned stored knowledge about events. Evidences from the present experiment show that also observing the action biases the perceptual analysis in favour of the action suitable stimulus dimension. However, one might argue that the modulator effect of the activated cognitive representation on the perceptual system depends on the actual goal of the individual. Indeed, the event coding is assumed to be tailored to the situational demands by means of setting and changing the relative weights of features codes. Thus, if a feature code is prominent for a given task, then its activation level will be increased, causing a priming of all the events with overlapping features (Hommel *et al.,* 2001). Here, it has been provided an example of such a process. Specifically, if participants were required to actively plan the action (i.e. grasping), then one might argue the activation level of the action-related stimulus dimension (i.e. size) was increased, as that stimulus dimension was immediately relevant for the successive execution of the planned action: this mechanism results in the motor-visual priming effect This could configure a case of active cognitive representation activation, driven by the intended behaviour. On the other hand, if participants were required to observe the action (i.e. grasping), then one might argue the activation level of the action-related stimulus dimension (i.e. size) was less enhanced than when participants have actively to perform that action, as the subject intended goal did not concern with the active performance of that action; rather, the subject intended goal concerns with the performance of the visual discrimination task. This could configure a case of passive cognitive representation activation (Rizzolatti & Craighero, 2004). Such a distinction can account for the motor-visual priming effect being showed to depend on the observer's perspective. Hence, altogether the findings from action planning and action observing seem to provide experimental evidence for the graduate enhancement of the cognitive representations being ascribed to the weighing feature principle. Of course, further investigations need to directly address this issue, being such a statement based on a post-hoc interpretation.

Finally, and most relevant to the specific aim of this study, the positive findings that came from action planning and action observing investigations support the hypothesis of a common coding shared across the action and the perception, as the motor-visual priming effect manifested on both the event perception and the event generation having the same phenomenical features.

3. CONCLUSIONS

The present study was aimed at investigating the nature of the cognitive representations of action, possibly underlying the activation of the mirror system in humans. In particular, according to the main assumption of the Theory of Event Coding it has been supposed that the representation of a to-be-perceived or a to-be-generated event deals with the activation of perceptual and motor feature codes in a common representational format (Hommel *et al.*, 2001). Taken together, the findings of the present study support such a statement, by showing that both action planning and action observing entailed a motor-visual priming effect. Specifically, both preparing or observing a grasping action made the stimulus size processing faster than the spatial location stimulus processing; conversely, both preparing or observing a pointing action made participants being faster in the spatial location stimulus processing than in the size stimulus processing. Intriguingly, such a result provides evidence the action preparation can prime the perceptual processing of also those stimuli that were completely un-related to the planned action, extending the scope of the priming effect of action found by others (e.g. Craighero *et al.*, 2002). More importantly, according to the anatomical and functional properties of the mirror system, the findings of this study provided an experimental proof of the existence of an internal action representation whose activation would mediate both the execution and the action observation (Rizzolatti and Craighero, 2004). Indeed, the findings showed some behavioural effects consistent with the idea of the cognitive representation claimed by the TEC's proponents. That is, when the individual is required to actively planning or observing the action, the cognitive representation provided the functional matching between the perception and the action systems by configuring the perceptual system in favour of the processing of the stimulus dimensions that are the best adapted to optimize the performance. Furthermore, the data from my study support the view of a cognitive representation of the event, which goes beyond a mere motor reproduction at a neural level of the observed, intended or imagined action (Jeannerod, 2001). Rather, it seems reasonable to think of the cognitive representation of the action as reflecting the activation of broadly tuned action knowledge, built up from a history of past interaction with the objects (Tucker and Ellis, 2004).

As discussed in the introduction, the notion of action-centred cognitive representations suggests the necessity to finely tune the components of the action which one is dealing with. In line with this view, the common coding approach and the theoretical systematization formulated by the Theory of Event Coding could be viewed as a potential candidate for such a specification, by providing the neurophysiologic level of investigation with a data-grounded cognitive model. Importantly, by considering the action in terms of its perceivable effects that are reflected in the action planning, the present study turns out in the progressive setting up of an experimental paradigm where the effects of the action on the perceptual processing was directly tested, thus achieving the second goal this study aimed to.

In conclusion, the present data empirically support the Theory of Event Coding as a comprehensive theoretical framework that, whilst accounting for most of the experimental evidences showing modulation effects between the action and the perception systems, on the other hand provides the cognitive neurosciences with a cognitive theoretical model through which the behavioural effects could be also investigated. More precisely, the Theory of Event Coding represents the starting point for further developing the cognitive model aimed at providing a theoretical framework for explaining the relationships between action and perception. Indeed, some aspects of the theory, for instance those concerning the feature binding process that glues both the action and the perception feature codes into the event file have still to be investigated. Furthermore, another issue that further investigations should address concerns the number of feature codes that can be bound at any moment into the event file. More generally some aspects of the event code, that is the core of the Theory of Event Coding, need to be further specified in order to make the apparent great explanatory potential of this cognitive model actual.

REFERENCES

Abrams, R. A. & Pratt, J. (2000). Retinal coding of inhibited eye movements to recently attended locations. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 776-788

Aglioti, S., DeSouza, J. F. X., & Goodale, M. (1995). Size-contrast illusions declive the eye but not the hand. *Current Biology, 5,* 679-685.

Allport, D. A. (1987). Selection for action: Some behavioural and neurophysiological considerations of attention and action. In H. Heuer & F. Sanders (Eds.), *Perspectives on perception and action*. Hillsdale, NJ: Erlbaum.

Bédard, M.A., Massioui, F.E., Pillon, B. & Nandrino, J.L. (1993). Time for reorienting of attention: A premotor hypothesis of the underlying mechanism. *Neuropsychologia*, *31,* 241-249.

Bernstein, L.J., Cooper, L.A. (1997). Direction of motion influences perceptual identification of ambiguous figures. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 721-737.

Blakemore, S. J., Wolpert, D. M., & Frith, C. D. (2002). Abnormalities in the awareness of action. *Trends in Cognitive Science*, *6*, 237-242.

Brass, M., Bekkering, H., Prinz, W. (2001). Movement observation affects movement execution in a simple response task. *Acta Psychologica, 106*, 3-22.

Bridgeman, B., Kirch, M., & Sperling, A. (1981). Segregation of cognitive and motor aspects of visual function using induced motion. *Perception & Psychophysics, 29*, 336-342

Bridgeman, B., Peery, S., & Anand, S. (1997). Interaction of cognitive and sensorimotor maps of visual space. *Perception & Psychophysics, 59,* 456-469.

Broadbent, D.E. (1958). *Perception and communication*. London: Pergamon Press.

Broadbent, D. E. (1971). *Decision and stress*. London: Academic Press.

Brunswik, E. (1944). Distal focussing of perception. Size constancy in a representative sample of situations. *Psychological Monographs, 56*, No. 1.

Buchtel, H.A., & Butter, C. M. (1988). Spatial attentional shifts: Implications for the role of polysensory mechanisms. *Neuropsychologia, 26,* 499-509.

Butter, C. M., Buchtel, H. A., & Santucci, R. (1989). Spatial attentional shifts: Further evidence for the role of polysensory mechanisms using visual and tactile stimuli. *Neuropsychologia, 27,* 1231-1240.

Castiello, U., Paine, M., & Wales, R. (2002). Perceiving an entire object and grasping only half of it. *Neuropsychologia. 40,* 145-151.

Castiello, U., Paulignan, Y. & Jeannerod, M. (1991) - Temporal dissociation of motor responses and subjective awareness: a study in normal subjects. *Brain, 114*, 2639-2655.

Cheal, M. & Lyon, D. R. (1991). Central and peripheral precuing of forced-choice discrimination. *Quarterly Journal of Experimental Psychology, 43 A*, 859-880.

Cherry, E. C. (1953). Some Experiments upon the recognition of speech with one and two ears. *Journal of the Acoustical Society of America, 25*, 975-979.

Conway, B. A., Halliday, D. M., Farmer, S. F., Shahani, U., Maas, P., Weir, A. I., & Rosenberg, J. R. (1995). Synchronization between motor cortex and spinal motoneural pool during the performance of a maintained motor task in man. *Journal of Physiology, 489*, 917-924.

Craighero, L., Bello, A., Fadiga L., Rizzolatti, G. (2002). Hand action preparation influences the responses to hand pictures. *Neuropsychologia, 40*, 492-502.

Craighero L., Fadiga L., Umilta C. A., Rizzolatti G. (1996). Evidence for visuomotor priming effect. *Neuroreport, 8,* 347–349.

Craighero, L., Fadiga, L., Rizzolatti, G., & Umiltà, C. A. (1998). Visuomotor priming. Visual *Cognition, 5,* 109–125.

Craighero, L., Fadiga, L., Rizzolatti, G., Umiltà, C. (1999). Action for perception: A motor-visual attentional effect. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 1673-1692.

Creem, S. H., & Proffitt, D. R. (1998). Two memories for geographical slant: separation and interdependence of action and awareness. *Psychonomic Bulletin and Review, 5*, 22-36.

Creem, S. H., Proffitt, D. R. (2001). Grasping objects by their handles: A necessary interaction between cognition and action. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 218-228.

Deutsch, J. A., Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological Review, 70,* 80-90.

Di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., Rizzolatti, G. (1992). Understanding motor events: A neurophysiological study. *Experimental Brain Research, 91,* 176-180.

Downing, C. J. & Pinker, S. (1985). The spatial structure of visual attention. In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance XI* (pp. 171-187), Hillsdale, NJ: Erlbaum.

Driver, J. & Spence, C. (1998). Attention and the crossmodal construction of space. *Trends in Cognitive Sciences, 2*, 254-262.

Edwards, M. G., Humphreys, G. W., Castiello, U. (2003). Motor facilitation following action observation: A behavioural study in prehensile action. *Brain and Cognition, 53*, 495-502.

Eimer, M., Cockburn, D., Smedley, B., & Driver, J. (2001). Cross-modal links in endogenous spatial attention are mediated by common external locations: Evidence from event-related brain potentials. *Experimental Brain Research, 139,* 398-411.

Eimer, M., Van Velzen, J., & Driver, J. (2002). Cross-modal interactions between audition, touch, and vision in endogenous spatial attention: ERP evidence on preparatory states and sensory modulations. *Journal of Cognitive Neuroscience, 14*, 254-271.

Ellis, R., & Tucker, M. (2000). Micro-affordance: the potentiation of components of action by seen objects. *British Journal of Psychology, 9*, 451–471.

Elsner, B., & Hommel, B. (2001). Effect anticipation and action control. *Journal of Experimental Psychology: Human Perception & Performance, 27*, 229-240.

Eriksen, C.W., Schultz, D.W., 1979. Information processing in visual search: A continuous flow conception and empirical results. *Perception & Psychophysics 25*, 249-263.

Fadiga, L. & Craighero, L. (2004). Electrophysiology of action representation. *Journal of Clinical Neurophysiology, 21,* 157-169.

Fadiga, L., Fogassi, L., Gallese, V., Rizzolatti, G. (2000). Visuomotor neurons: ambiguity of the discharge or 'motor' perception? *International Journal of Psychophysiology, 35,* 165-177.

Fagg, A. H., Arbib, M. A. (1998). Modeling parietal-premotor interactions in primate control of grasping. *Neural Networks, 11*, 1277-1303.

Ferlazzo, F., Padovani, T., Couyoumdjian, A., Olivetti Belardinelli, M., (2002). *The Quarterly Journal of Experimental Psychology: Human Experimental Psychology 55A*, 937-963.

Gallese, V., Fadiga, L., Fogassi, L., Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain, 119*, 593-609.

Gibson, E. J. (1977). The theory of affordances. In R. E. Shaw & J. Bransford (Eds.), *Perceiving, acting, and knowing*. Hillsdale, NJ: Erlbaum.

Gibson, J. J., (1979). *The ecological approach to visual perception*. Trad. Italiana: Un approccio ecologico alla percezione visiva. Il Mulino, 1999.

Goodale, M. A., Humphrey, G. K. (1998). The objects of action and perception. *Cognition, 67,* 181-207.

Goodale, M. A., Jakobson, L. S., Milner, A. D., Perrett, D. I., Benson, P. J., Hietanen, J.K. (1994). The nature and limits of orientation and pattern processing visuomotor control in a visual form agnosic. *Journal of Cognitive Neuroscience, 6*, 46–56.

Goodale, M. A., & A. D. Milner. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences, 15*, 20-25.

Grafton, S. T., Fadiga, L., Arbib, M. A., Rizzolatti, G. (1997). Premotor cortex activation during observation and naming of familiar tools. *Neuroimage, 6,* 231-236.

Grèzes, J., Decety, J. (2002). Does visual perception of object afford action? Evidence from a neuroimaging study. *Neuropsychologia, 40,* 212–222.

Grèzes, J., Tucker, M., Armony, J., Ellis, R., & Passingham, R. E. (2003). Objects automatically potentiate action: an fMRI study of implicit processing. *European Journal of Neuroscience, 17,* 2735-2740.

Haggard, P. (2001). The psychology of action. *British Journal of Psychology, 92*, 113-128.

Hamilton, Wolpert & Frith (2004) Your own action influences how you perceive another person's action. *Current Biology 14,* 493-498

Heider, F. (1926/1959). Thing and medium. *Psychological Issues* 1959 Monograph 3 (original work published 1926).

Heider, F. (1930/1959). The function of the perceptual system. *Psychological Issues* 1959 Monograph 371-394. (original work published 1930).

Held, R. (1968). Dissociation of visual functions by deprivation and rearrangement. *Psychologische Forschung*, *31*, 338-348.

Hommel, B. (1996). The cognitive representation of action: Automatic integration of perceived action effects. *Psychological Research/Psychologische Forschung, 59*, 176-186.

Hommel, B. (2004). Event files: Feature binding in and across perception and action. *Trends in Cognitive Sciences, 8*, 494-500.

Hommel, B., Müsseler, J., Aschersleben, G., Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences, 24,* 849-878.

Houghton, G, Tipper, S. P.(1996). Inhibitory mechanisms of neural and cognitive control: Applications to selective attention and sequential action. *Brain and Cognition, 30,* 20-43.

Hughes, H. C. & Zimba, L. D. (1985). Spatial maps of directed visual attention. *Journal of Experimental Psychology: Human Perception and Performance, 11*, 409-430.

Hughes, H. C. & Zimba, L. D. (1987). Natural boundaries for the spatial spread of directed visual attention. *Neuropsychologia, 25*, 5-18.

James, B. (1890). *Principles of psychology*. New York, Holt.

Jeannerod, M. (1994). The representing brain: Neural correlates of motor intention and imagery. *Behavioral and Brain Sciences, 17*, 187-245.

Jeannerod, M. (1997). *The cognitive neuroscience of action*. Oxford, England: Blackwell.

Jeannerod (1999) Commentary on: A. David Milner & Melvyn A. Goodale. (1995) *The Visual Brain in Action.* (Oxford Psychology Series, No. 27). Oxford: Oxford University Press

Jeannerod, M. (2001). Neural simulation of action: A unifying mechanism for motor cognition. *NeuroImage, 14*, S103-S109.

Jeannerod, M, Arbib, MA, Rizzolatti, G, Sakata, H (1995) Grasping objects - the cortical mechanisms of visuomotor transformation. *Trends in Neurosciences, 18*, 314-320.

Jeannerod, M., Decety, J., Michel, F. (1994). Impairment of grasping movements following a bilateral posterior parietal lesion. *Neuropsychologia, 32,* 369-80.

Kahneman, D., & Treisman, A. (1984). Changing views of attention and automaticity. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of attention* (pp. 29-61). San Diego, CA: Academic Press.

Kahneman, D., Treisman, A., & Gibbs, B. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology, 24*, 175-219.

Klein, R. (1980). Does oculomotor readiness mediate cognitive control of visua attention? In R. S. Nickerson (Ed.), *Attention and Performance VIII* (pp. 259-276). Lawrence Erlbaum Associates , Hillsdale, NJ.

Kunde, W. (2001). Response-effect compatibility in manual choice reaction tasks. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 387-394.

Lotze, R. H. (1852). *Medicinische Psychologie oder Physiologie der Seele*. Leipzig: Weidmann.

Macaluso, E., Eimer, M., Frith, C.D., & Driver, J. (2003). Preparatory states in crossmodal spatial attention: Spatial specificity and possible control mechanisms. *Experimental Brain Research, 149,* 62-74.

Macaluso, E., Frith, C. D., & Driver, J. (2001). Multimodal mechanisms of attention related to rates of spatial shifting in vision and touch. *Experimental Brain Research, 137,* 445-454.

Macaluso, E., Frith, C. D., & Driver, J. (2002a). Supramodal effects of covert spatial orienting triggered by visual or tactile events. *Journal of Cognitive Neuroscience, 14*, 389-401.

Macaluso, E., Frith, C. D., & Driver, J. (2002b). Directing attention to locations and to sensory modalities: Multiple levels of selective processing revealed with PET. *Cerebral Cortex, 12*, 357-368.

Macaluso, E., Frith, C. D., & Driver, J. (2002c). Crossmodal spatial influences of touch on extrastriate visual areas take current gaze direction into account. *Neuron, 34,* 647-658.

Mack, A., Rock, I. (1998). *Inattentional blindness: Perception without attention.* Cambridge, MA: MIT Press.

Marzke, M. W. (1997). Precision grips, hand morphology and tools. *American Journal of Physical Anthropology, 102*, 91–110.

McClelland, J. L. (1979). On the time relations of mental processes: An examination of systems of processes in cascade. *Psychological Review, 86,* 287–330.

McClelland, J. L., Rumelhart, D. E., & the PDP Research Group (1986). *Parallel distributed Processing: Psychological and biological models (Vol. 2).* Cambridge, MA: MIT Press.

McDonald, J. J., & Ward, L. M. (2000). Involuntary listening aids seeing: Evidence from human electrophysiology. *Psychological Science, 11*, 167-171.

Miller, J., 1982. Discrete versus continuous stage models of human information processing: In search of partial output. *Journal of Experimental Psychology: Human Perception and Performance 8,* 273-296.

Miller, J., 1988. Discrete and continuous models of human information processing: Theoretical distinctions and empirical results. *Acta Psychologica 67*, 191-257.

Milner A.D. & Goodale M.A. (1995) *The visual brain in action*. Oxford; New York, Oxford University Press.

Milner, A. D., Perrett, D. I., Johnston, R. S., Benson, P. J., Jordan, T. R., Heeley, D. W., Bettucci, D., Mortara, F., Mutani, R., Terazzi, E., & Davidson, D. L. W. (1991). Perception and action in visual form agnosia. *Brain, 114*, 405–428.

Mondor, T. A. & Amirault, K. J. (1998). Effect of same-and different-modality spatial cues on auditory and visual target identification. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 745-755.

Mondor, T. A., & Zatorre, R. J. (1995). Shifting and focusing auditory spatial attention. *Journal of Experimental Psychology: Human Perception and Performance, 21*, 387-409.

Moray, N. (1959). Attention in dichotic listening: Affective cue and the influence of instructions. *Quarterly Journal of Experimental Psychology, 11*, 56-60.

Napier, J. R. (1960). Studies of the hands of living primates. *Proceedings of the Zoological Society of London, 134*, 647–656.

Neumann, O. (1987). Beyond capacity: A functional view of attention. In H. Heuer & A. F. Sanders (Eds.), *Perspectives on perception and action* (pp. 361-394). Hillsdale, NJ: Erlbaum.

Neumann, O. (1990). Visual attention and action. In O. Neumann & W. Prinz (Eds.), *Relationships between perception and action: Current approaches* (pp. 227-267). Berlin, New York: Springer.

O'Regan, J. K., Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences, 24*, 939-1011.

Paccalin, C. Jeannerod, M. (2000).Changes in breathing during observation of effortful actions. *Brain Research, 86*, 194–200.

Pavani, F., Boscagli, I., Benvenuti, F., Rabuffetti, M., & Farné, A. (1999). Are perception and action affected differently by the Titchner circles illusion? *Experimental Brain Research, 127*, 95-101.

Posner, M.I. (1980). Orienting of attention. *The Quarterly Journal of Experimental Psychology. 32,* 3-26.

Posner, M. I., Cohen Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (eds.), *Attention and performance, X: Control of language Processes*. (pp. 531-556), Hillsdale, New Jersey: Erlbaum.

Prinz, W. (1990). A common coding approach to perception and action. In O. Neumann, & W. Prinz (Eds.), *Relationships between perception and action* (pp. 167-201). Berlin: Springer Verlag.

Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology, 9,* 129-154.

Reuter-Lorenz, P. A. & Fendrich, R. (1992). Oculomotor readiness and covert orienting: Differences between central and peripheral precue. *Perception and Psychophysics, 52*, 336-344.

Rizzolatti, G. & Craighero, L. (2004). The mirror-neuron system. Annual Review of *Neurosciences, 27,* 169-192.

Rizzolatti, G., Riggio, L., Dascola, I., & Umiltà, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favour of a premotor theory of attention. *Neuropsychologia, 25*, 31-40.

Rizzolatti, G., Riggio, L. & Sheliga, B. M. (1994). Space and selective attention. In C. Umiltà, M. Moscovitch (Eds.), *Attention and Performance, XV. Conscious and Nonconscius Information Processing* (pp. 231-265), Cambridge, Massachusetts: MIT Press;

Rosenbaum, D. A. (1980). Human movement initiation: Specification of arm, direction and extent. *Journal of Experimental Psychology: General, 109*, 475-495.

Rosenbaum, D. A. (1987). Successive approximations to a model of human motor programming. *Psychology of Learning and Motivation, 21,* 153-182.

Rosenbaum, D. A., Inhoff, A. W. & Gordon, A. M. (1984). Choosing between movement sequences: a hierarchical editor model. *Journal of Experimental Psychology: General, 113,* 372-393.

Rosenbaum, D. A., Kornblum, S. A. (1982). A priming method for investigating the selection of motor responses. *Acta Psychologica, 51*, 223-243.

Rossetti, I. (1998). Implicit short-lived motor representation of space in brain-damaged and healthy subjects. *Consciousness and Cognition, 7, 520*-558.

Rossetti, Y. & Pisella, L. (2002). Several different "vision for action" systems: A guide to dissociating and integrating dorsal and ventral functions. In W. Prinz & B. Hommel (Eds.), *Attention and performance XIX: Common mechanisms in perception and action.* Oxford, UK: Oxford University Press.

Rumelhart, D. E., McClelland, J. L., & the PDP Research Group (1986). *Parallel distributed processing: explorations in the microstructure of cognition. Foundations (Vol. 2).* Cambridge, MA: MIT Press.

Scheerer, E. (1984). Motor theories of cognitive structure: A historical review. In W. Prinz & A. F. Sanders (Eds.), *Cognition and motor processes* (pp. 77-97). Berlin: Springer.

Schmidt, R. A. (1988). *Motor control and learning* (2nd ed.). Champaign, IL: Human Kinetics Publishers

Schmitt, M., Postma, A. & De Haan, E. (2000). Interactions between exogenous auditory and visual spatial attention. *The Quarterly Journal of Experimental Psychology, 53 A*, 105-130.

Schneider, G. E. (1969). Two visual systems. *Science, 28,* 895-902.

Schubotz, R., I., Friederici, A., D., Yves von Cramon, D. (2000). Time perception and motor timing: A common cortical and subcortical basis revealed by fMRI. *NeuroImage, 11,* 1-12.

Schubotz, R., I., Yves von Cramon, D. (2001). Functional organization of the lateral premotor cortex: fMRI reveals different regions activated by anticipation of object properties, location and speed. *Cognitive Brain Research, 11*, 97-112.

Schubotz, R., I., Yves von Cramon, D. (2002). Predicting perceptual events activates corresponding motor schemes in lateral premotor cortex: An fMRI study. *NeuroImage, 15,* 787-796.

Schubotz, R., I., Yves von Cramon, D. (2003). Functional-anatomical concepts of human premotor cortex: Evidence from fMRI and PET studies. *NeuroImage, 20*, S120-S131.

Shepherd, M., Findlay, J. M., Hockey, R. J. (1986). The relationship between eye mevements and spatial attention. *Quarterly Journal of Experimental Psychology, 38A*, 475-491.

Shulman, G. L., Remington, R. W., & McLean, J. P. (1979). Moving attention through visual space. *Journal of Experimental Psychology: Human Perception and Performance, 5,* 522-526.

Simon, J. R. (1969). Reactions toward the source of stimulation. *Journal of Experimental Psychology,* 81, pp. 174-176.

Smyth, M. M., & Pendleton, L. R. (1990). Space and movement in working memory. *The Quarterly Journal of Experimental Psychology, 42A,* 291–304.

Spence, C. J. & Driver, J. (1996). Audiovisual link in endogenous covert spatial attention. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 1005-1030.

Teder-Sälejärvi, W. A., Münte, T. F., Sperlich, F. J., & Hillyard, S. A. (1999). Intra-modal and cross-modal spatial attention to auditory and visual stimuli. An event-related brain potential study. *Cognitive Brain Research, 8,* 327-343.

Tipper, S. P., Brehaut, J. C. & Driver, J. (1990). Selection of moving and static objects for the control of spatially directed action. *Journal of Experimental Psychology: Human Percept ion and Performance, 16,* 492-504.

Tipper, S. P., Howard, L. A. & Houghton, G. (1999). Action-based mechanisms of attention. In G. W. Humphreys, J. Duncan & A. Treisman (Eds.). *Attention, space and action* (pp. 231-247). Oxford: University Press.

Tipper, S. P., Lortie, C. & Baylis, G. C. (1992). Selective reaching: Evidence for action-centered attention. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 891-905.

Tipper, S. P., Weaver, B., Jerreat, L. M. & Burak, A. L. (1994). Object-based and environment-based inhibition of return of visual attention. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 478-499.

Tipper, S.P., Weaver, B., Kirkpatrick, J., & Lewis, S. (1991). Inhibitory mechanisms of attention: Locus, stability, and relationship with distractor interference effects. *British Journal of Psychology, 82,* 507-520.

Treisman, A. (1960). Contextual cue in selective listening. *The Quarterly Journal of Experimental Psychology, 12*, 242-248.

Treisman, A., (1964). Selective attention in man. *British Medical Bulletin, 20,* 12-16

Treisman, A. (1999). Feature binding, attention and object perception. In G. W. Humphreys, J. Duncan, A. Treisman (Eds.). *Attention, space and action* (pp. 91-111). Oxford: University Press.

Treisman, A., Gelade, G. (1980). A feature integration theory of attention. *Cognitive Psychology, 12,* 97-136.

Treisman, A., Schmidt, H. (1982). Illusory conjunctions in the perception of object. *Cognitive Psychology, 14*, 107-141.

Trevarthen, C. B. (1968). Two mechanisms of vision in primates. *Psychologische Forschung, 31,* 299-337.

Tsal, Y. (1983). Movements of attention across the visual field. *Journal of Experimental Psychology: Human Perception and Performance, 9,* 523-530.

Tucker, M., Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 830-846.

Tucker, M., Ellis, R. (2004). Action priming by briefly presented objects. *Acta Psychologica, 116*, 185-203.

Ungerleider L.G., Mishkin M. (1982). Two cortical visual systems. In M.A. Goodale, R.J.W. Mansfield (Eds.): *Analysis of visual behaviour*. The MIT Press, Cambridge, MA: pp. 549-586.

Van der Heijden, A. H. C. (1992). *Selective attention in vision*. London: Routledge.

Vogt, S., Taylor, P., Hopkins, B. (2003). Visuomotor priming by pictures of hand postures: perspective matters. *Neuropsychologia, 41*, 941-951.

Ward, L. M. (1994). Supramodal and modality-specific mechanisms for stimulus-driven shifts of auditory and visual attention. Canadian Journal of Experimental Psychology, 48, 242-259.

Ward, R. (2002). Independence and integration of perception and action: An introduction. *Visual Cognition, 9*, 385-391.

Wohlschlager, A. (2001). Mental object rotation and the planning of hand movement. *Perception & Psychophysics, 63,* 709-18.

Wohlschlager, A. (2000). Visual motion priming by invisible actions. *Vision Research, 40,* 925-930.

Woodin, M.E., & Heil, J. (1996). Skilled motor performance and working memory in rowers: Body patterns and spatial positions. *The Quarterly Journal of Experimental Psychology, 49A,* 357–378.

Ziessler M, Nattkemper D (2002) Effect anticipation in action planning. In W. Prinz, B. Hommel (Eds.), *Common mechanisms in perception and action: Attention & Performance XIX.* Oxford University Press, Oxford, pp. 645-672