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CICLO XXI

ACTING
SOCIAL INTENTIONS

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1. General Introduction

1.1 Social cognition

In the last few decades there have been enormous advances in our understanding of the links between the mind, the brain, and behaviour. Sensory systems have been explored in detail leading to a much greater understanding of the mechanisms underlying visual perception (Zeki, 1993). We also know much more about the mechanisms by which our motor system allow us to reach and grasp objects (Jeannerod, Arbib, Rizzolatti, & Sakata, 1995). However, a striking feature of these approaches is that people are considered as strictly isolated units. In contrast, we spend most of our time thinking about and interacting with other people rather than looking at abstract shapes and pushing buttons. To investigate this issue experiments are needed in which people interact with one another rather than behave in isolation. It is this kind of experimental approach and how it can be nested within the 'social cognition' domain which constitutes the main core of my thesis.

The study of social interaction involves by definition a bi-directional perspective and is concerned with the question of how two minds shape each other mutually through reciprocal interactions. The most well-known and influential social psychology studies are controlled experiments that illustrate the power of social interaction without ever creating any natural contact between the interacting individuals (e.g. the apparently fatal electric-shock experiment performed by Milgram, 1974). There is no doubt that this and similar experiments have taught us much about the nature of social influence. However, the experimental methodology of the individual subject faced with pre-programmed confederate has stifled the study of dyadic processes.

The present thesis provides an attempt to indagate interactive minds and the mechanisms underlying such phenomenon from a behavioural perspective by adopting a motor control approach.

As we know from the literature there is a dedicated neural system in the brains of primates for detecting and interpreting biological motion (Oram and Perret, 1996). Both developmental and neurophysiological researches suggest a common coding between perceived and generated actions. Movements that are being observed can be used for multiple purposes. First, the observation might lead to internal simulation in order to understand the behaviour that is being observed (Rizzolatti & Craighero, 2004). Second, the observed movements might form the basis for prediction as to what an actor might do in the near future (Csibra, 2008). Third, the internally simulated movements might provide clues as to the intentions associated with the observed behaviour (Iacoboni, Molnar-Szakacs, Gallese, Buccino, Mazziotta, & Rizzolatti, 2005). Fourth, observed movements may provide a global scaling parameter of ones own future actions, specifically if these actions are complementary to those performed by the actor that is being observed. But how the transition from perception to action is carried out? And how we can read and decode others' goals and intentions?

Below I shall report on one of the classic theoretical frameworks put forward to explain the link between perception and action, i.e., the Ideomotor Theory (James, 1890). Then I shall provide some arguments regarding how such classic theorizing has evolved into a bi-directional account which entails how the link between perception and action might be modulated by social intentions which in turn are translated into motor programmes during dyadic social interactions.

1.2 PERCEPTION AND ACTION

"How can a motor act be constructed from a perceived act?"

(Prinz, 1987)

1.2.1 The Ideomotor Theory

Action is defined as the movement produced to satisfy an intention towards a specific goal, or in reaction to a meaningful event in the physical and social environment. The notion that actions are intrinsically linked to perception goes back to the 19th century.

An interesting suggestion concerning the relationship of perceived and executed action was given by James with the description of what he called ideomotor action (James, 1890). James formulated this idea as follows: "Every representation of a movement awakens in some degree the actual movement which is its object" (James, 1890). Greenwald (1970) elaborated on this idea his theory of ideomotor action. He stated that (a) voluntary responses are represented centrally in the form of images of the sensory feedback they produce, and (b) such images play a controlling role in the performance of their corresponding actions. From this perspective it becomes clear how action observation can be used to guide action execution. Due to a similarity relation, observing an action activates the response image of the corresponding response.

The ideomotor theory postulates that at a certain representational level the actions planned and the actions observed are functionally equivalent (Knoblich & Flach, 2001).

1.2.2 The Observation-Execution Matching System

The discovery of "mirror neurons" in the ventral premotor cortex of the macaque monkey provided the first physiological evidence for a direct matching between action perception and action execution (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992). Evidence for a matching system in humans are cumulating, but experts still debate whether this "mirror system" uses specialized motor representations or general processes of visual inference and knowledge to understand observed actions. Observing someone else's action allows us to understand what the observed agent is doing. Two possible brain mechanisms have been proposed to explain this ability. On the one hand, the observer's brain might contain a specialized system for understanding actions, based on representing the motor commands required to make the action. On the other hand, the brain might understand actions using the same general perceptual, inferential, and theory-building processes that are used to understand other objects and their interactions. Calvo-Merino and her colleagues showed that observing an action evokes a purely motor representation (Calvo-Merino, Grezes, Glaser, Passingham, & Haggard, 2006). In this functional magnetic resonance imaging (fMRI) study male and female expert dancers viewed videos of gender-specific male and female ballet moves. Some ballet moves are performed by only one gender. However, male and female dancers have equal visual familiarity with all moves. fMRI revealed greater premotor, parietal, and cerebellar activity when dancers viewed moves from their own motor repertoire, compared to opposite-gender moves. This result shows that "mirror" circuits have a purely motor response above visual representations of action. We understand actions not only by visual recognition, but also motorically. The matching system offers a parsimonious explanation of how I understand the actions of others: by a direct mapping of the visual representation of the observed action into a motor representation of the same action.

Observing an action can activate the corresponding motor representation.

The similarity between an observer's and an actor's action representations might determine the degree to which resonance occurs in the observer. For instance, resonance is higher when one has a high level of expertise at performing the observed actions (Calvo-Merino et al., 2006), or perceives one's own previously performed actions (Knoblich & Flach, 2003). However, to interact successfully with others, it is often not sufficient to understand what they are doing at a given moment in time. Instead, being able to predict outcomes of others' actions and knowing what others are going to do next is crucial. Several findings suggest that motor resonance also supports action prediction (Kilner, Vargas, Duval, Blakemore, & Sirigu, 2004). For instance, a recent study on patterns of eye–hand coordination showed that when individuals observed a person stacking blocks, their gaze preceded the action and predicted a forthcoming grip, just like when they performed the block-stacking task themselves (Flanagan & Johansson, 2003).

1.2.3 Shared Representations

One theoretical consequence of the equivalence between perception and action is that we must hypothesise the existence of a level of neural representations that are neutral in terms of agent and modality of activation (the same representation is activated in different action modalities, e.g., when an individual executes an action, observes another individual performing the same action, or simply imagines doing the action). As Jeannerod (2003) noted, neural representations are shared not only by the same structures for different types of action, i.e., executed and observed action, but also by different brains. When two agents interact socially with one another, the activation of 'mirror' networks creates a shared neural representation - i.e., representations simultaneously activated in the brains of two agents. Given that self-generated actions and other people's actions are mapped onto the same neural substratum, the same representations are activated in both agents. Beside, a series of recent studies has shown that individuals form 'shared representations' of tasks almost automatically, even when it is more effective to ignore one another. In one of these studies, pairs of participants performed a 'go – no go' task sitting alongside each other with no interpersonal coordination being requested. Surprisingly, each actor integrated the co-actor's action alternative in his or her action planning, even when the other's actions could not be observed (Sebanz, Knoblich, & Prinz, 2005): an action-selection conflict occurred when a stimulus required an action from both actors, each of whom acted according to a different stimulus–response mapping. This suggests that (i) each person knew what the other should do, and (ii) the other's task was represented in a functionally equivalent way to one's own. Evoked related potentials (ERP) measurements on no-go trials showed increased response inhibition when a stimulus required the other's response compared with trials in which no response was required. This indicates that a representation of the action to be performed was activated following stimulus presentation, and was then suppressed to avoid acting when it was the other's turn. In the light of these findings, it is tempting to speculate that the ability to form shared representations of tasks is a cornerstone of social cognition. It allows individuals to extend the temporal horizon of their action planning, acting in anticipation of others' actions rather than simply responding.

1.2.4 Beyond the Ideomotor Theory: Joint Actions

During action observation a corresponding representation in the observer's action system is activated. It has been suggested, however, that actions are not purely coded in terms of motor properties of the observed movement, but rather in terms of action goals (Umiltà, Kohler, Gallese, Fogassi, Fadiga, Keysers, & Rizzolatti, 2001). This could help to establish procedural common ground in joint action. As a working definition, joint action can be regarded as any form of social interaction whereby two or more individuals coordinate their actions in space and time to bring about a change in the environment. Successful joint action depends on the abilities (i) to share representations, (ii) to predict actions, and (iii) to integrate predicted effects of own and others' actions. The joint activity of two or more individuals can be understood as an autonomous, self-organized, and functionally defined perception-action system. A model of joint action by Oztop, Wolpert, and

Kawato (2005) that makes relevant claims regarding joint-action coordination in sequential task performance presumes that when a person observes someone else's actions she automatically will activate her own action system not only to understand the behaviour of the actor being observed (Rizzolatti et al., 2004) but also to infer that actor's intentions (Wolpert, Doya, & Kawato, 2003; Iacoboni et al., 2005).

The ability to coordinate our actions with those of others is crucial for our success as individuals and as a species. Even seemingly simple joint actions, like carrying a heavy object together, are challenging in that two individual bodies and minds must be coordinated. In an intriguing series of experiments, Richardson and colleagues (2005) asked pairs of participants to lift wooden planks off a conveyer belt. The planks varied in length such that they could be lifted by a single person, or only by two individuals. It was expected that participants would switch to joint lifting at some point as the planks got longer. This transition point reflects to what extent co-actors take each other's action capabilities into account. It was found that the transition point varied as a function of a pair's mean arm span. This finding provides evidence that the perceived affordance of objects is governed not only by what individuals believe they can do, but also by what they believe they can do with others. How is this actually achieved? To reach a more comprehensive understanding of the processes underlying social interaction, one needs to move on from studying the processing of social stimuli towards investigating real-time social interactions. Moreover, studies on joint action challenge the assumption traditionally held in cognitive psychology that perception, action, and higher-level cognitive processes can be understood by investigating individual minds in isolation. Knowing what the other is attending to in a particular action context provides important cues about the other's action goals and can elicit complementary actions in the observer as outlined below.

1.2.5 Complementary Actions and the Bi-Directional Account

A hallmark of complex cognitive agents is their ability to cooperate with others in order to achieve an individual or mutual goal. While this type of interpersonal behaviour requires individuals to consciously think, make decisions, and solve problems, they must also detect relevant perceptual information and coordinate their movements in the service of these goals.

Although joint action sometimes requires imitative kinds of movement, in other circumstances the goal can only be accomplished by making 'complementary' movements. This can only be achieved if activation of motor representations following observation is suppressed, so that one can perform actions dissimilar from those observed. Humans are indeed remarkably good at coordinating their actions to reach common goals.

What are the mechanisms supporting complementary actions? According to ideomotor theories, perceiving events produced by others' actions should activate the same representational structures that govern one's own planning of these actions, as observed in mimicry, priming, and imitation (see Paragraph 1.2.1). However, in many situations people do not perform identical actions, but carry out complementary actions. It has not been investigated so far what happens when one acts alongside another person performing not the same, but a complementary action. Perhaps the most important feature to be understood is how individuals adjust their actions to those of another person in time and space. Clearly, this cannot be explained just by the assumption that representations are shared. Although motor resonance and task sharing allow individuals to predict others' actions, it remains unclear how they would go from predicting another's action to choosing an appropriate complementary action at an appropriate time.

Recent studies have advanced our knowledge about the processes integrating self and other in a bi-directional account by revealing how individuals incorporate the timing of others' actions in their own action planning. Interacting partners must plan and execute their actions in relation to what they predict the other will do rather than respond to observed actions.

Knoblich and Jordan (2003) investigated the mechanisms underlying such anticipatory coordination with a tracking paradigm, in which participants kept a circle on a moving target jointly or individually. The results demonstrate that feedback about the timing of another's actions can become as effective for anticipatory action control as internal signals about one's own actions. Receiving unambiguous feedback about each other's timing enabled participants in the group to plan ahead, because each member learned to predict the timing of the other's actions. Action coordination is achieved by integrating the 'what' and 'when' of others' actions in one's own action planning. It is tempting to speculate that the joint effect arises on a level at which one's own actions and others' actions are represented in a functionally equivalent fashion.

Many questions remain to be addressed in future research, as the study of complementary actions has only recently started to gain broader attention. Most importantly, future studies should investigate the mechanisms whereby individuals coordinate their actions online (see Chapter 7). This is particularly challenging, because the mutual influences of two or more actors' intentions on each other must be assessed. Moreover, it will help to fill a gap in current theorizing about the social nature of cognition, which so far has drawn mainly on studies that have investigated how solitary individuals respond to static stimuli.

1.3 INTENTIONALITY

The capacity to understand conspecific's intentions provides considerable benefits to individuals, as they can help to predict other's actions. The term intentionality has traditionally been used by philosophers (e.g., Brentano, Husserl) to refer to a state about or directed toward another state. Intentionality constitutes a wide notion overarching different sorts of mental states: in order to be classifiable as Intentional any mental state or event has to be about or directed at something in the world.

More recently, this term has come to be used more narrowly as a derivative of the verb intend and implies doing something on purpose (Feldman & Reznick, 1996). Here, we apply the quality intentional to an agent's actions when an observer believes that the actions are based on some degree of awareness and are executed deliberately.

1.3.1 Searle's Dual Theory of Intention

According to the classical version of the Causal Theory of Action[1], what distinguishes actions from mere happenings is the nature of their causal antecedents. However, this simple version of the Theory is faced with a difficulty: many actions, in particular automatic ones, do not seem to be preceded by any intention to perform them, at least if the intention is meant to be conscious.

In order to answer this problem, Searle (1983) proposed that we distinguish between two types of intentions, what he calls 'intentions in action' and 'prior intentions'. In Searle's terminology, a 'prior intention' (see Paragraph 1.2.2.1) corresponds to the initial representation of the goal of the action prior to the initiation of the

[1] The Causal Theory of Action has been a popular approach to understanding both the nature of actions and the explanation of actions. The most prominent proponents of the Causal Theory are Davidson, 1963, 1973, 1978, and Goldman, 1970. The origin of the current interest in Causal Theory can be traced back to Davidson's 1963 paper 'Action, Reasons and Causes'.

action. However, it is not enough that a movement be caused by a prior intention in order to be qualified as an action. It is moreover required that the movement be caused by an intention-in-action (see Paragraph 1.2.2.2), that proximately triggers the physiological chain leading to overt behaviour.

The label 'intention-in-action' is indeed quite appropriate in that it highlights an important aspect of this conception of causation of action, namely that the intention does not terminate with the onset of the action but continue until the action is completed. On this view, the intention does not simply trigger the action, it plays a continuing causal role in shaping the action, guiding and monitoring it until completion.

1.3.1.1 Prior Intention

Some actions are premeditated or involve deliberation: prior intention is defined as the intention formed prior to the action that is its condition of satisfaction.

If, for Searle, action is a causal and intentional transaction between mind and the world, then the prior intention can be said to initiate the transaction by representing, before action is undertaken, the action as a whole. Accordingly, the action as a whole is the condition of satisfaction of the prior intention. Because the prior intention bears a causal relation to the action as a whole, it transitively bears a causal relation to the intention-in-action, which forms the mental component internal to the action and which in turn causes the bodily movement associated with the action.

Searle depicts this graphically as:

Action

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prior intention -> intention-in-action -> movement

Searle (1983) writes about the “relative indeterminacy of prior intentions” meaning that when intending something we do coordinate a possible set of events towards a final goal. But this set of events is modifiable by way of its being confirmed or infirmed during the course of action. The final goal acts as a focal point for this permanent monitoring, re-evaluation and re-coordination, and it is the only necessary event in the package.

1.3.1.2 Intention in Action

Searle (1983) introduces the operatory notion of ‘intentions in action’ in order to account for the executive dimension of intentions. By doing so he introduces a kind of “bi-dimensionality” to the very notion of “intention”, somewhat akin to the political separation of legislative (“prior intentions”) and executive (“intentions in action”) powers. The argument is that not all intentions are formed prior to the actual action being taken place. Some intentions emerge and evolve during the performance of a given action (see Chapter 7).

Intentions in action never seem to exhaust in themselves, which is what Searle suggests with his idea that "We just act": they are always transitive experiences of acting.

1.3.2 Understanding Other's Intentions

By observing people acting we can usually say what they are doing and what their goals are (Baldwin & Baird, 2001). We can frequently even imagine the reason why they are acting.

Intentions may be understood on the basis of action observation but also with the support of eye gaze (see Chapter 7). Accumulative empirical evidence suggests that recognising the intentions of others is based, at least in part, on the same mechanisms underlying the formation of one's own motor intention (Frith, 2002). The idea is that the same cortical areas that are activated when we execute an action are also activated when we observe other people performing a similar action.

1.3.3 Individual and Social Intentions

Tuomela (2002) claims that a particular aspect of intention – the "aim intention" - determines the mode of the intention. Consider the case of an agent, John, lightening a candle. John may light a candle because the electricity has gone out, or to celebrate Independence Day. In the first case, John is acting in the pursuit of a merely private goal, driven by an I-mode intention; in the latter case, lighting a candle satisfies a shared we-attitude. The action is the same, and so is the author. What changes is the "mode" of intention: "I-mode" means acting and having an attitude privately, as a private person, whereas "we-mode" means having it as a group member (see Chapter 3).

Even a communicative intention is necessarily social, for it involves taking other people into account, as part of one's reasons for acting (Tuomela & Bonnevier-Tuomela, 1997). In contrast to private intention, which can be realised by an isolated person, a communicative intention can occur only during social interaction (Bosco, Bucciarelli, & Bara, 2004). According to Cognitive Pragmatics (Bara, 2005), however, communicative intentions represent a "special" sort of social intention, consisting not only of the intention to communicate meaning, but also of the intention that this first intention should be recognised by the addressee (see Chapter 4).

1.4 A UNIFIED FRAMEWORK FOR MOTOR CONTROL AND SOCIAL INTERACTION

Movement is the only way we have of interacting with the world. Direct information transmission between people is mediated through the motor system which provides a common code for communication. The proposal is that other's actions are decoded by activating one's own action system at a sub-level and there appears to be a special neural mechanism for decoding such information. The study of motor control is fundamentally the study of sensorimotor transformations. We can view the motor system as forming a loop in which motor commands cause muscle contractions, with consequent sensory feedback, which in turn influences future motor commands (Wolpert & Ghahramani, 2000) (see Figure 1.1a). Motor control is, therefore, concerned with inputs and outputs from a controlled object (e.g., the arm) that is a part of our own body. When interacting with another person we can think of an analogous social interaction loop (see Figure 1.1b) in which the controlled object is the other person. Our motor commands cause muscle contractions and these generate communicative signals, such as speech or gesture. When perceived by another person these can have influences on their hidden mental state, which determine their behaviour.

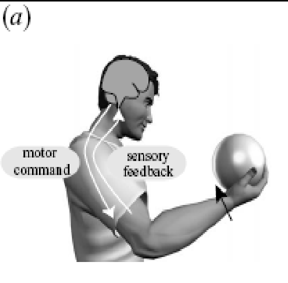
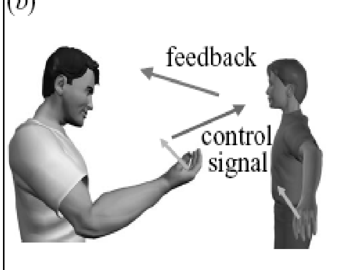
	motor control	social interaction
loop	(*a*) 	(*b*) 
control signal	motor command	communicative actions e.g. speech, gesture
consequences	change in my body's state	change in your mental state
state	configuration of my body	mental state of your mind

Figure 1.1 The sensorimotor and social interaction loops. The motor control loop (a) involves generating motor commands that cause changes in the state of my own body. Depending on this new state and the outside world I receive sensory feedback. The social interaction loop (b) involves me generating motor commands that cause communicative signals. These signals when perceived by another person can cause changes in their internal mental state. These changes can lead to actions which are, in turn, perceived by me. (Adapted from Wolpert et al., 2000)

In the present thesis I extended the kinematic approach for motor control to the domain of social interaction.

In particular, I examined how social intention are translated into actions, whether specific kinematic patterns connote and distinguish actions executed with social goals from actions motivated by individual goals, and the extent to which unexpected social requests can override pre-planned actions. To this end I adopted the reach-to-grasp movement as experimental window. Why this kind of action provides an ideal mean for investigating the processes at stake here is outlined below.

1.5 THE EXPERIMENTAL WINDOW: THE REACH-TO-GRASP MOVEMENT

"The mind makes the hand, the hand makes the mind"

(H. Focillon, 1947)

The human hand is a highly complex structure that in many ways defies understanding. The modern study of human hand movements has been pioneered by the British evolutionary biologist John Napier (1956). An important tenet of Napier's theorization is that how our hands interact with objects not only depends on object features, but it strictly depends on the intentions guiding the action.

Marc Jeannerod (1981; 1984), was amongst the first to systematically analyse the dynamic aspects of prehension with the use of high speed cinematographic techniques, providing a quantitative description for such movements. Jeannerod described two major components for prehensile behaviour: the transport and the grasp components. The transport component brings the hand in the vicinity of the object. The grasp component is concerned with fingers' pre-shaping during transport and fingers' closing around the object. But how the CNS (central nervous system) plans the upcoming event?

The planning process involves three aspects:

- Perceiving task-specific object properties
- Selecting a grasp strategy, and
- Planning a hand location and orientation

Choosing an appropriate motor plan depends on information perceived about the object.

1.5.1 Effects of Object Properties on Reaching and Grasping

A number of studies have investigated the effects of intrinsic object properties on hand kinematics suggesting that the object's features have an effect on hand aperture (Steenbergen, Marteniuk, & Kalbfleisch, 1995; Smeets & Brenner, 1999). The level of accuracy with which an object is grasped depends on object weight, texture, etc. Altogether the studies had shown that the need for more firm hand-object contact points translates into the determination of a safety margin which is operationalized through an increase of the thumb-index distance and an increase in reach duration. Bootsma, Marteniuk, Mackenzie and Zaal (1994) also indagated the speed-accuracy trade-off in manual prehension. With respect to the grasp component, both object size and object widths are shown to affect peak hand aperture (see Chapter 2). Smaller object widths give rise to longer movement times. Increasing object width, instead, lowers the spatial accuracy demands on the transport component, permitting a faster movement to emerge. At the same time, the hand opens to a larger grip in order to compensate for eventual directional errors that result. Recent studies have also investigated how the aim of an action is able to modulate the action pattern, but experimental manipulations were restricted to the physical environment within which the movement occurred. A challenging, almost unexplored question is whether kinematic adjustments can also be noticed when changes are applied to the social environment in which the action takes place.

1.5.2 Reach-To-Grasp and Social Context

In a remarkable study Mason and Mackenzie (2005) explored the reach-to-grasp movement when passing an object to a partner. Participants worked in pairs during the experiment: one partner, playing the role of passer, transported an object forward or held the object at an interception location. The second partner, playing the role of receiver, waited at an interception location or reached toward the passed object. Kinematic results indicated that receivers were sensitive to the motion of the object as they reached to make contact. During object transfer, it was noted that somatosensory control was used by both the passer and receiver to precisely coordinate transfer rate.

Furthermore, in a recent study Zheng, Swanström and Mackenzie (2007) investigated whether in complex surgery tasks the work should be distributed between two operators or accomplished bimanually by one operator. The authors hypothesized that superior task performance results when two operators work collaboratively in a dyad team as opposed to one operator performing the task bimanually. Shorter durations of total task time were indeed shown for the dyad than for the single bimanual operators. This result indicates the superior role of team collaboration, as compared with the single operator. Higher frequency of anticipatory movement was observed in the dyad team, which led to superior performance for team collaboration, as compared with that of the single operator. Performance of anticipatory movements in the dyad team was explained by a shared mental model, which postulates combined capacity for information processing among team members.

Along these lines, two basic modes of social cognition, namely cooperation and competition, have started to be systematically investigated with a kinematic approach (Georgiou, Becchio, Glover & Castiello, 2007). In one experiment, for the 'cooperation' tasks two participants were requested to reach and grasp their respective objects and to cooperate to join the two objects in specific configurations in the middle of the working surface. For the ‘competition’ tasks, the two participants had to compete to place their own object first in the middle of the working surface. Results revealed specific kinematic patterns for cooperation and competition which were distinct from similar actions performed by each participant in isolation. Further, during the cooperation tasks, a high level of correlation between key kinematical parameters of the two participants was found. These results suggest the existence of motor patterns which reflect the intention to act in a social context.

1.6 THE PRESENT RESEARCH

Kinematic patterns vary depending on the context in which the action takes place. Here I applied the kinematics approach to better understand interpersonal perception and action, and how social goals are incorporated into action plans, a process which has yet to be fully elucidated. First, I investigated whether and how prior social intentions are embedded into specific kinematic patterns (see Chapters 3 and 4). Then I translated these notions within a more cognitive domain considering the effects that implicit biases such as gender and race prejudices may have on the kinematics of the participants during an interactive task (see Chapter 5). Continuing on this analysis, I investigated the kinematic patterns adopted during cooperation vs. competition tasks, by looking at the effects that an actor instructed to infringe the rules of cooperation/competition may have on her partner’s kinematic patterns (see Chapter 6). Finally, in order to test the effects of social intentions on the online control of action, I carried out an experiment in which a human agent seated next to the participant performed a social perturbation, which is a sudden and unexpected gesture (e.g. unfolding the hand as to ask for the object. See Chapter 7). Specifically, the first experiment described in Chapter 7 tested whether human gestures conveying a social request modify pre-planned actions by online integration of other's actions. The remaining three experiments included within this chapter were control experiment aimed at disentangling the role played by social, biological and attentive factors in such endeavour. In the first control experiment (see Paragraph 7.3) the human agent was replaced by a robotic device. The second control experiment (see Paragraph 7.4) not only manipulated the biological factor, but also the communicative value conveyed by the gesture. The last experiment (see Paragraph 7.5) investigated the role played by the agent's gaze in transmitting intentional cues. Altogether these experiments provide some understanding of how the motor system reacts to different types of unexpected events and how it deals with the requirement of a fast reorganization.

The obtained results have been discussed in light of current theories proposed to explain integration processes of self and other's actions in social contexts (see the 'Discussion' sections for each experimental chapter and the 'Final Considerations' section in Chapter 8).

"Men work together," I told him from the heart,

"Whether they work together or apart."

Robert L. Frost

2. General methods

In this chapter the methods and the procedures which are common to all experiments included in the present thesis will be described.

2.1 Participants' Characteristics

All the participants who took part in the present series of experiments showed right-handed dominance (Oldfield, 1971), and reported normal or corrected-to-normal vision. They were naïve as to the purpose of the experiments and. gave informed written consent to participate in the studies. The experimental procedures were approved by the Institutional Review Board at the University of Padova and were in accordance with the declaration of Helsinki.

2.2 Apparatus and Procedures

In all the experiments participants were tested individually in a dimly lighted room. The working surface was a rectangular table (150 x 100 cm). The participant was seated on a height adjustable chair so that the thorax pressed gently against the front edge of the table and the feet were supported. The starting position implied the ulnar side of the hand placed upon a starting pad (see Figure 2.1), with the tip of the index and the tip of the thumb in contact with each other, the shoulder slightly flexed, and a semipronation of the forearm, 5-10° wrist extension. The starting pad was attached 3 cm away from the edge of the table on the mid-sagittal axis 15 cm anterior to the participant's midline (see Figure 2.1). Infrared reflective markers (0.25 mm diameter) were taped to the following points on the participants' right upper limb: (1) wrist – dorsodistal aspect of the radial styloid process; (2) thumb – ulnar side of the nail; and (3) index finger – radial side of the nail (see Figure 2.2). Before each trial, the right hand of each participant rested on the starting pad (brown velvet cloth 7 x 6 cm). The target location was delimited by a brown velvet cloth (8 x 8 cm) placed in the middle of the table (see Figure 2.1).

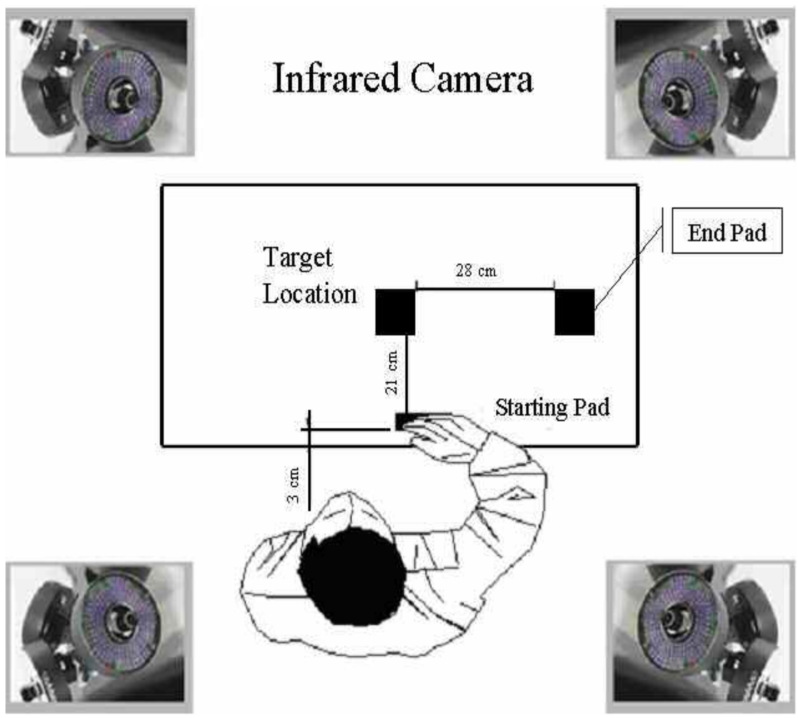


Figure 2.1 Schematic representation of the experimental set-up. Four infrared cameras recorded the displacement of the 3 markers placed on the right hand. Three pads – starting pad, target pad and end pad – located on the working surface refer to the starting position of the right hand, the target position and the end of the movement.

A concave base (12 cm diameter) was located over the end pad (brown velvet cloth 6 x 7 cm) to the right of the target at a distance of 28 cm (see Figure 2.1).

Participants were instructed to start the action after a tone (880 Hz/200 ms) was presented. Then, they were requested to reach and grasp the target object located at 30 cm from the hand starting position (see Figure 2.1), using the distal pads of the thumb and index finger.

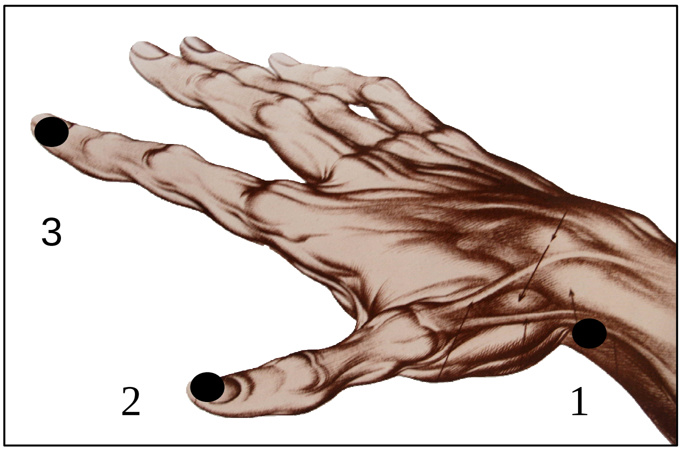


Figure 2.2 Schematic representation of the infrared reflective marker on the considered anatomical landmarks. (1) wrist – dorsodistal aspect of the radial styloid process; (2) thumb – ulnar side of the nail; and (3) index finger – radial side of the nail.

2.3 Recording Techniques

Movements were recorded by using an ELITE motion analysis system (Bioengineering Technology & Systems [B|T|S]) (see Appendix I). Four infrared cameras (sampling rate 100 Hz) placed 120 cm away from each of the four corners of the table (see Figure

2.1) captured the movement of the markers in 3D space. Co-ordinates of the markers were reconstructed with an accuracy of 0.2 mm over the field of view. The standard deviation of the reconstruction error was 0.2 mm for the vertical (Y) axis and 0.3 mm for the two horizontal (X and Z) axes.

2.4 Data Processing

After data collection, the TRACKLAB software package (B|T|S|) was used to analyse the raw data for all trials for each participant as to provide a 3-D reconstruction of the marker positions as a function of time (see Appendix II). The wrist marker was used to measure the reaching component of the action, whereas the finger and the thumb markers were used to measure the grasp component of the action.

2.5 Measures of interest

Following the 3-D reconstruction procedures, we considered for analysis the dependent measures which have already shown variations when comparing individual versus social attitudes (e.g., Georgiou et al., 2007).

In general, the task involved an action which was performed in two phases, a 'reach-to-grasp' phase and a subsequent 'place' phase. The latter involved either a concave plastic base or a co-experimenter's hand (see 'Method' section for each specific experiment). Kinematics for these two phases were analysed separately. The parameters concerned with the grasp component were obviously considered only for the reach-to-grasp phase. Conversely parameters concerned with the reaching component were analysed for both movement phases.

Specifically, for the first 'reach-to-grasp' phase I considered:

(I) Movement time. The interval between the onset of the movement, and the time at which the fingers came in contact with the object. (see Figure 2.3a),

(II) The Amplitude of Peak Wrist Velocity (PWV). The amplitude of maximum velocity of the wrist during the reaching phase (see Figure 2.3a),

(III) Deceleration time. The time from peak velocity to the end of the movement (see Figure 2.3a),

(IV) The Amplitude of Peak Trajectory (PT). The amplitude of the maximum height of the wrist trajectory from the working surface (see Figure 2.3d),

(V) The Time of Peak Deviation (PD). The time at which the maximum curvature of the arm trajectory path was reached with respect to an ideal line linking the starting position with the target object (see Figure 2.3c).

(VI) The Time of Peak Grip Velocity (PGV). The time at which the fingers reached the maximum velocity during the opening phase (see Figure 2.3b).

(VII) The Amplitude of Peak Grip Velocity (PGV). The maximum amplitude reached by the fingers during the opening phase (see Figure 2.3b).

(VIII) The Time of Maximum Grip Aperture (MGA). The time at which the index finger's and thumb's markers reached the maximum distance (see Figure 2.3b).

(IX) The Amplitude of Maximum Grip Aperture (MGA). The amplitude of the maximum distance between the two markers positioned on the index finger and the thumb (see Figure 2.3b),

For the 'place' phase, the following dependent measures were considered:

(X) The Time to Peak Wrist Velocity (PWV). The time of maximum wrist velocity of during the placing phase (see Figure 2.3a).

(XI) The Amplitude of Peak Wrist Velocity (PWV). The amplitude of maximum velocity of the wrist (see Figure 2.3a).

(XII) The Time to Peak Trajectory. The time at which the wrist trajectory reaches the maximum height from the working surface

(XIII) The Amplitude of Peak Trajectory (PT). The amplitude of the maximum height of the wrist trajectory from the working surface during the placing phase.

(XIV) The Trajectory Path. The length of the wrist trajectory (see Figure 2.3d).

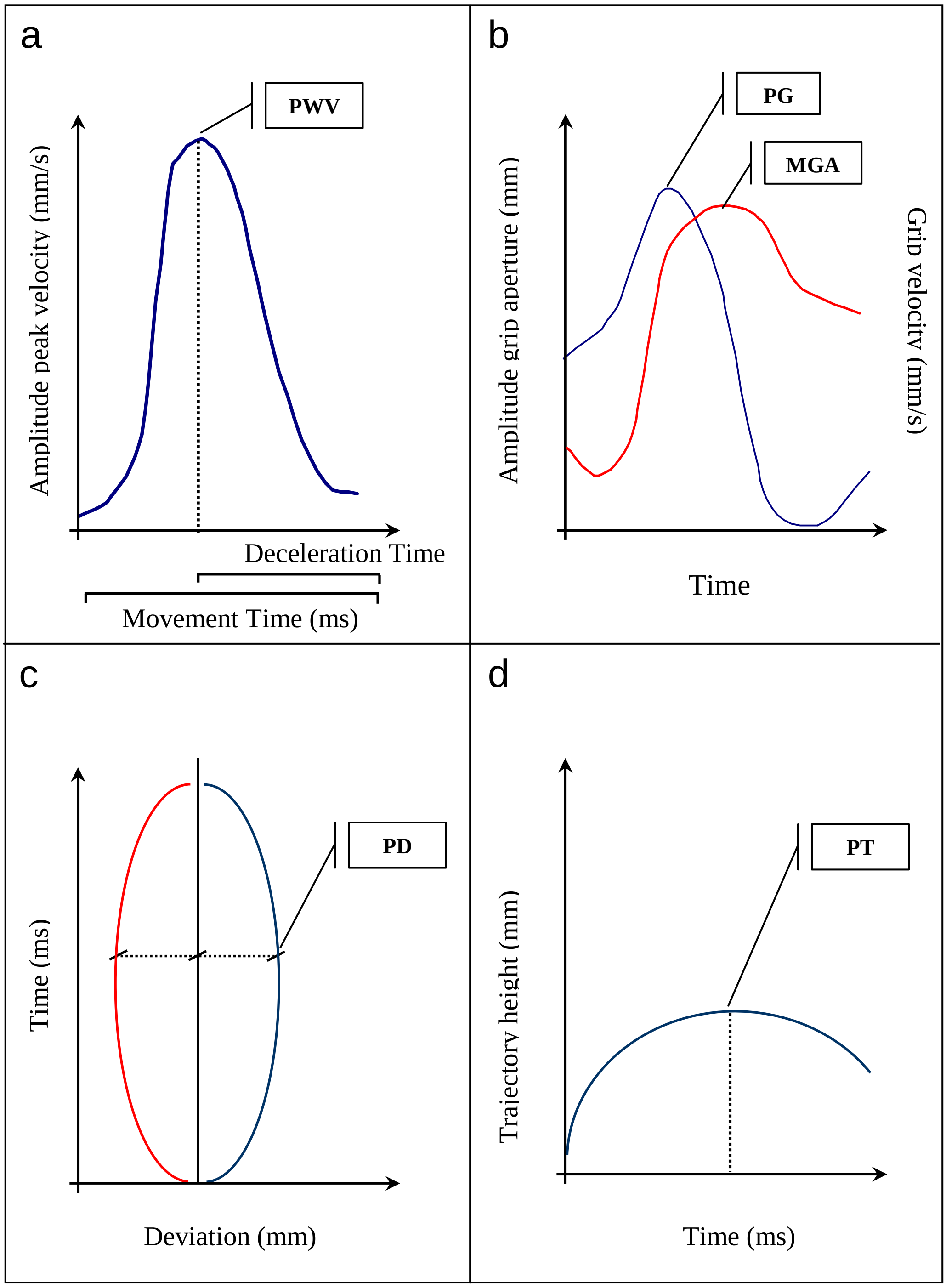


Figure 2.3 Wrist and aperture profiles as a function of time. The dependent measures considered for the reaching component are the wrist velocity profile (panel 'a', blue line), the deceleration time (panel 'a'), and the peak deviation (panel 'c') with respect to the ideal line linking the starting position with the target object. For the grasp component grip aperture (panel 'b', red line) and grip velocity (panel 'b', blue line) as a function of time are considered. For the 'place' phase the peak deviation (panel 'c') and trajectory height (panel 'd') are considered.

Given that we expect the patterns for social vs. non-social action to differ with respect to movement speed, possible kinematical differences may be better understood when the occurrence of kinematical events are expressed in relative terms (as a percentage of the overall movement time). Therefore, each temporal value for both the reach and the grasp components will be considered in both absolute and relative values.

2.6 DATA ANALYSIS

For each dependent variable, the means for each participant were entered into analyses of variance (ANOVA). Post-hoc comparisons were carried out using t-test. Bonferroni correction was applied (alpha level: 0.05). Preliminary analyses were conducted to check for normality, sphericity (Mauchly test), linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multicollinearity. The analyses have been carried out by using Statistical Package for Social Sciences (SPSS).

Please note that within the 'Data analysis' section for each experiment included within the present thesis I shall consider only those parameters which, on the basis of the specific experimental hypothesis, might prove to be sensitive to the experimental manipulation under discussion.

3. THE CASE OF DR. JEKYLL AND MR. HYDE: A KINEMATIC STUDY ON SOCIAL INTENTION[2]

Abstract

In the present study we investigated the effect of social intention on kinematics. Specifically, we asked participants to produce intentional actions in two different contexts provided by either an individual or a social task. For the individual task, participants were requested to act in isolation (single-agent condition). They were requested to reach towards and grasp an object and to move it from one spatial location to another. For the social task participants were requested to reach towards and grasp the same object as for the 'individual' task, but to pass it to a partner (social condition). We also included a 'passive-observer' condition as to exclude that possible differences might be simply due to the presence of another person. The results indicate a specific kinematic pattern for social intention, which differed from that obtained for the 'single agent' and the 'passive-observer' condition.

[2] *Published*: Becchio, C., Sartori, L., Bigheroni, M., & Castiello U. (2008). The case of Dr. Jekyll and Mr. Hyde: a kinematic study on social intention. *Consciousness and Cognition, 17,* 557-564.

3.1 Introduction

Does the motor system play any role in understanding social intentions?

According to simulation theory, motor processes underlie the execution of actions as well as the understanding of other's people intended action (e.g. Decety & Grèzes, 2006; Jackson & Decety, 2004; Gallese 2001, 2003; Gallese & Goldman, 1998).

A controversial issue is whether the same mechanism of motor simulation may account for our understanding of social intentions, i.e. intentions directed at other persons.

Jacob and Jeannerod (2005) propose the following thought-experiment. Consider Dr. Jekyll and Mr. Hyde. The former is a renowned surgeon who performs appendectomies on his patients. The latter is a dangerous sadist who performs exactly the same hand movements on his victims. Dr. Jekyll's social intention clearly differs from Mr. Hyde's: whereas Dr. Jekyll intends to improve his patient's medical condition, Mr. Hyde intends to derive pleasure from his victim's agony. Social intentions, is claimed, stand to actions in a many-one relation: the very same action can be at the service of different social intentions (Jacob, 2006). The question addressed by the present study concerns the plausibility of this many-one assumption. Is it possible that different social intentions correspond to exactly the same external movements?

It has been demonstrated that intention mechanisms modulate motor activation (Castiello, Lusher, Mari, Edwards, & Humphreys, 2002; Castiello, 2003; Edwards, Humphreys, & Castiello, 2003). In addition, Georgiou and colleagues (2007) revealed kinematics patterns for cooperative and competitive behaviour, which were distinct from those obtained by the same participants for movements having similar requirements in terms of speed and accuracy, but performed in isolation.

In the present study we ask whether kinematics is sensitive to the social intention to affect the behaviour of another person.

3.2 METHOD

3.2.1 Participants

Thirteen students (11 women and 2 men, ages 20 – 31 years) took part in the experiment.

3.2.2 Stimulus

The stimulus was an egg-shape object (long axis = 5,7 cm; weight ~ 50 g) positioned on the target pad (see Chapter 2) at a distance of 25 cm from the hand starting position along the midsagittal plane (see Figure 3.1).

3.2.3 Procedures

Participants were requested to start the action after a tone (880 Hz/200 ms) was presented. There were three experimental conditions:

- Single agent. Each participant was requested to reach towards, grasp the stimulus, and put it in the concave base (see Chapter 2) positioned at his/her right side (see Figure 3.1a). After each trial, the participant re-positioned the stimulus on the initial target location. Note that the base was given a concave shape matching the hand shape adopted by the experimenter during the 'social' condition (see below).

- Social. Each participant was requested to reach towards, grasp the stimulus, and pass it to a partner (see Figure 3.1b). The partner was seated to the far right side of the table with the hand supine resting on the end-pad. The partner received the object and then re-positioned it on the initial target location.

- Passive observer. Each participant performed the same action as for the "single agent" condition, but in the presence of a passive observer seated at the far right side of the table simply observing the scene. After each trial, the participant re-positioned the stimulus on the initial target location.

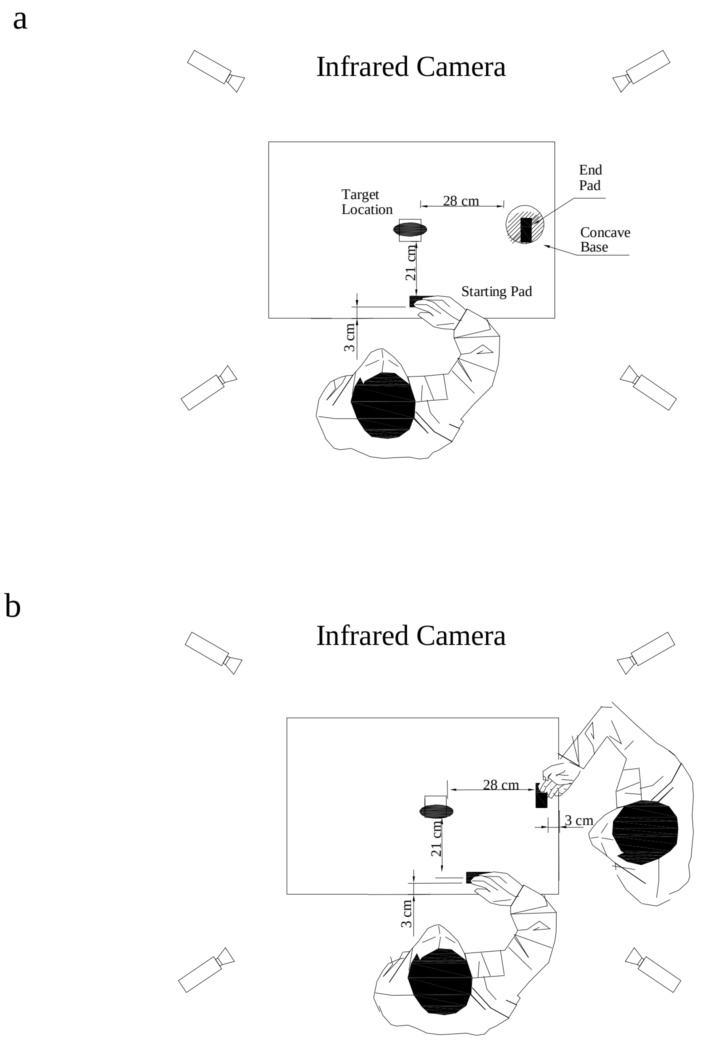


Figure 3.1 Graphical representation of the experimental set up for the single agent condition (panel 'a') and the social condition (panel 'b'). The concave base is transparent as to show that it was located on top of the end-pad (panel 'a').

The order of conditions was randomised between participants. Each subject performed 10 trials for each condition.

3.2.4 Data Analysis

To test for possible differences in kinematics as a function of experimental condition we performed an analysis of variance

(ANOVA) with experimental condition (single agent, social and passive observer) as within-participants factor.

3.3 RESULTS

3.3.1 Reach-To-Grasp Phase

In this phase the main factor experimental condition was statistically significant for the amplitude of maximum grip aperture [$F_{(2,12)} = 3.7$, $p < .05$] and the amplitude of peak grip opening velocity [$F_{(2,12)} = 3.8$, $p < .05$]. Post hoc contrasts revealed that maximum hand aperture and the amplitude of peak grip closing velocity were lower for the social than for the single agent condition (63 vs. 65 mm; 206 vs. 232 mm/s, respectively; $p_s<0.05$).

3.3.2 Place Phase

The main factor experimental condition was significant for amplitude of wrist trajectory height [$F_{(2,12)} = 24.1$, $p < .001$], length of wrist trajectory [$F_{(2,12)} = 10.3$, $p < .05$], amplitude [$F_{(2,12)} = 8.9$, $p < .001$] and time of peak velocity [$F_{(2,12)} = 4.3$, $p < .05$]. Post-hoc comparisons revealed that the wrist pathway was longer and the wrist trajectory height was higher for the 'social' than for the 'single agent' condition [$p_s < .01$; see Figure 3.2a-b]. Furthermore, amplitude and time of peak velocity were lower and earlier for the 'social' than for the 'single agent' condition [$p_s < .05$; see Figure

3.2c-d]. No significant differences were found when comparing the 'single agent' and the 'passive observer' conditions.

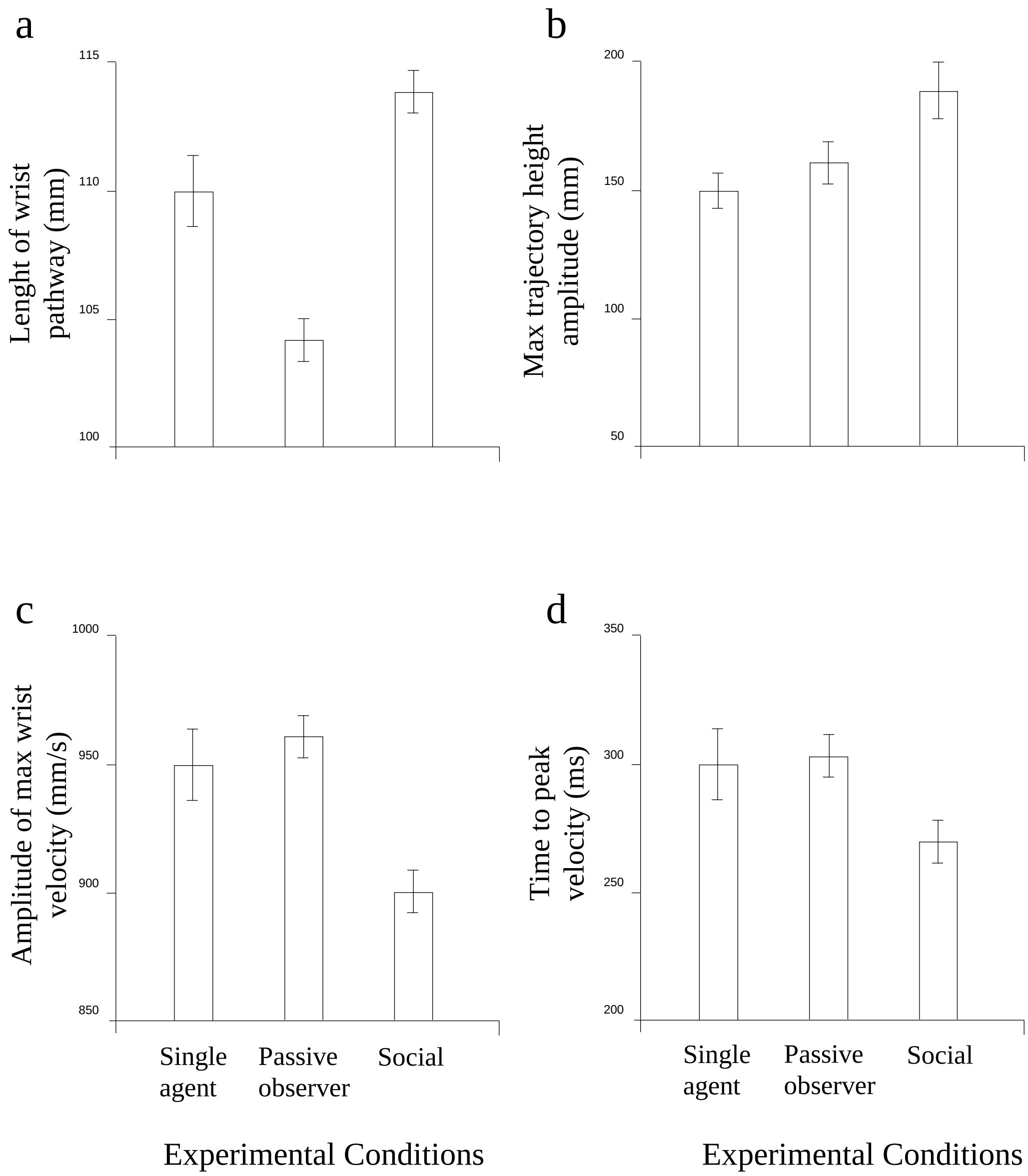


Figure 3.2 A graphical representation of the differences between the 'single agent', 'social' and 'passive observer' conditions for the parameters wrist trajectory height (panel 'a'), length of pathway (panel 'b'), amplitude of peak velocity (panel 'c') and time to peak velocity (panel 'd'). Bars represent the standard error.

3.4 DISCUSSION

In this study we investigated the effect of intention on the performance of the action of grasping an object and translating it from one spatial location to another location. This motor sequence could be executed with the intention to simply move the object (individual condition) or to pass it to a partner (social condition).

In line with our prediction, results revealed specific motor patterns for individual intended actions and actions motivated by a social intention. In particular, both the 'reach-to-grasp' and the 'place' phase were sensitive to the experimental manipulation. For the reach-to-grasp phase two key parameters, the amplitude of maximum grip aperture and the speed at which the hands open were found to be different for the 'social' condition. For instance, a lower speed of fingers' closure for the 'social' condition may signify that participants needed to compute a more careful approach when passing the object to another person. This would be necessary as to grasp the object in a manner which is appropriate for passing it to another person. In contrast, when the object had to be placed in the concave base ('single agent' condition) the determination of the contact points for the fingers might not be so crucial. This is because the object could be placed in the concave base in whatever orientation without compromising the goal of the action. Therefore the speed of finger closure can be faster. In kinematics terms these results are in line with recent evidence showing a more careful modulation of hand shaping depending on the end-goal accuracy (Ansuini, Santello, Tubaldi, Massaccesi, & Castiello, 2007).

As for the 'reach-to-grasp' phase the kinematics for the 'place' phase was different for the 'social' than for the 'single-agent' condition. Specifically, the results are suggestive of a more careful handling phase when the goal is nested within a social interaction. For example, a higher point of maximum trajectory height and an anticipated time to peak velocity are both indicative that a longer deceleration phase has been applied. In other words, the action of passing an object into the hand of another person entails a more careful action than when the same object is placed within an inanimate container. This result is remindful of previous kinematics evidence suggesting that placing an object within a fragile container entails a longer deceleration phase than when placing the same object within a robust container (Marteniuk, Mackenzie, Jeannerod, Athenes & Dugas, 1987). The conventional view assumes that the difference between a social and an individual action lies exclusively in the mental component (e.g. Jacob & Jeannerod, 2005; but see also Searle, 1998). The present findings show how differences in intentions are reflected in the kinematics: specific kinematical patterns connote and distinguish an action executed with a social goal from an action motivated by an individual goal.

It might be said that these differences in kinematics are dictated by diverse end- goal accuracy constraints. We propose two possible reasons as to rule out such an alternative explanation. First, the shape, size, and location of the base for the single agent condition matched the shape, size and location of the experimenter's hand for the social condition. Second, and more importantly, despite no physical difference occurred in the reach-to-grasp phase across the two conditions, significant differences emerged. For instance, in line with what found for the place phase, the lower amplitude of peak grip opening is indicative of a more careful approach towards the object. These differences are suggestive of an influence of social intention on kinematics: the intention to affect the behaviour of another person shapes the kinematics of the action.

4. DOES THE INTENTION TO COMMUNICATE AFFECT KINEMATICS?[3]

Abstract

The aim of the present study was to investigate the effects of social communication on action. Participants were requested to reach towards, grasp an object, and either simply lift it (individual condition) or lift it with the intent to communicate to a partner a predefined sequence meaning a word (communicative condition). Movements' kinematics was recorded using a three-dimensional motion analysis system. The results indicate that kinematics is sensitive to communicative intention. Movements performed for the 'communicative' condition were characterized by a kinematical pattern which differed from those obtained for the 'individual' condition. Results are discussed in terms of communicative intention theories and current knowledge on how social behaviour shapes action kinematics.

[3] Sartori, L., Becchio, C., Bara, B., & Castiello, U. (under revision). Does the intention to communicate affect action kinematics? *Consciousness and Cognition*.

4.1 INTRODUCTION

By definition, intentions are committed to actions. Moving up in the hierarchy of intentions, the relationship between intention and action appears, however, to become looser. On the one hand, the same intention could translate into different actions. On the other hand, the same action could serve different intention. Consider, for example, the action of turning off the light by pressing a switch. Depending on the agent's beliefs in specific circumstances (whether the light is on or off), this action could either serve her prior intention to turn the light on or off.

Criticizing motor theories of social cognition, Jacob and Jeannerod (2005; Jacob, 2006) extended these considerations to social intentions, i.e. intentions directed towards another agent, and communicative intentions, claiming that one and the same action could serve different (incompatible) social/communicative intentions. The case of communicative intention is somehow emblematic. Actions (e.g. goal-directed actions) are per se non-communicative. Nonetheless, every action could in principle become communicative when agents agree that it has a communicative status (Bara, 2007). For example, the action of touching one's earlobe – which is not communicative – could become communicative in the context of a poker card game, when two players agree that touching the earlobe means: "Drop out the current hand". An unexplored question is whether the imposition of a communicative meaning to an action affects action kinematics, i.e. how the action itself is implemented at motor level. Hierarchical models of action representation (e.g. Hamilton & Grafton, 2007; Wohlschlager, Gattis, & Bekkering, 2003), postulates different levels of motor control, relatively independent from each other. Common to different approaches is the idea of a progressive refinement, from an intentional level, to an object-goal level and finally to a kinematics level, which represents the actions required to achieve the goal. Whereas much is known about the organization of the lower levels, only a few studies have attempted to examine higher levels of motor control (e.g. Grafton & Hamilton, 2007). For example, little is known about how kinematical parameters (kinematics level) are influenced by the organized set of intention that one may entertain (intentional level) when performing the same object-directed action. In the present study, we examine this issue by focusing on communicative intention. Does the intention to communicate affect the parameterisation of the action? Is the intention to communicate reflected in the action kinematics? To answer these questions we asked participants to perform the same goal-directed action in two different contexts: an individual task and a communicative task. In the individual task, participants were requested to reach towards, grasp and lift either a blue or a green spherical object according to one of five predetermined sequences. The communicative task was identical to the individual task except that participants executed the sequence with a communicative intent. Each of the sequences of blue and green spheres represented a different meaning in a sort of simplified Morse code. Participants were asked to select a meaning (and thus a sequence) and to communicate it to a partner by lifting the spheres in the predetermined order. Based on a conversion table, the partner had to interpret the meaning of the communicated sequence. What we were interested in was to ascertain whether the effect of communicative intention reflected on the manner of how the spheres were reached towards and grasped.

4.2 METHOD

4.2.1 Participants

Ten subjects (7 women and 3 men, mean age 24 years) participated in the experiment.

4.2.2 Stimuli

Stimuli were two plastic spheres (diameter: 4 cm, weight: 5g) one blue and one green positioned on a black table at a 30 cm distance from the hand starting pad along the midsagittal plane.

4.2.3 Procedure

Participants were presented with five colour sequences drawn on a paper sheet. Each sequence was characterized by a specific colour's combination (e.g. green, blue, blue, green). They were instructed to choose four out of the five sequences and decide an order of presentation. Depending on the condition the sequence list was linked to a list of worlds (see Figure 4.1b) or not (see Figure 4.1a).

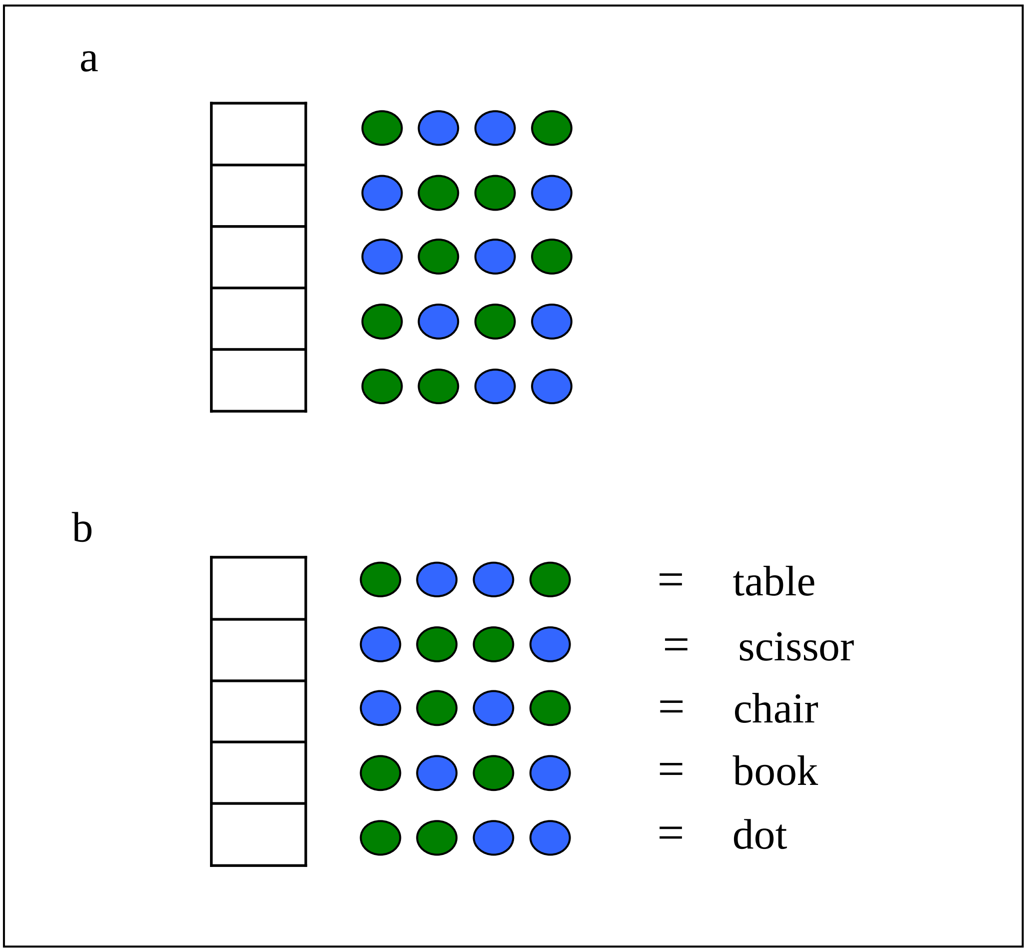


Figure 4.1 Participants were presented with either a sequence list of five colour's combinations (panel 'a') or a sequence list in which every colour's combination was related to a world (panel 'b').

The task was to reach, grasp and lift the spheres on the basis of the colour order characterizing each sequence. Movement began as soon as a tone (880 Hz/200 ms) was presented. There were two experimental conditions:

- Individual condition. In this condition, the participant was instructed to reach, grasp and lift the spheres in the order dictated by the sequences (see Figure 4.2a).
- Communicative condition. In this condition, two participants (a naïve subject and a co-experimenter) were seated opposite to each other (see Figure 4.2b, first panel from the left). Both were given a written note in which each of the five sequences corresponded to a word. Participants were made to believe that the co-experimenter was just another naïve participant. The task for the participants was to reach towards, grasp and show to the co-experimenter one of the sequences by using the coloured spheres as to allow her to decipher the word corresponding to the sequence (see Figure 4.2b, last panel). We included five different sequences in order to avoid that the co-experimenter could guess the last word by exclusion.

4.2.4 Data Analysis

A one-way analysis of variance (ANOVA) with experimental condition (individual, communicative) as a within-subjects factor was performed for each dependent measure. Preliminary analyses revealed that the stimuli' colour (blue or green) did not bring to any significant difference in kinematics. Therefore data for the data for 'blue' and 'green' stimuli have been collapsed.

a

b

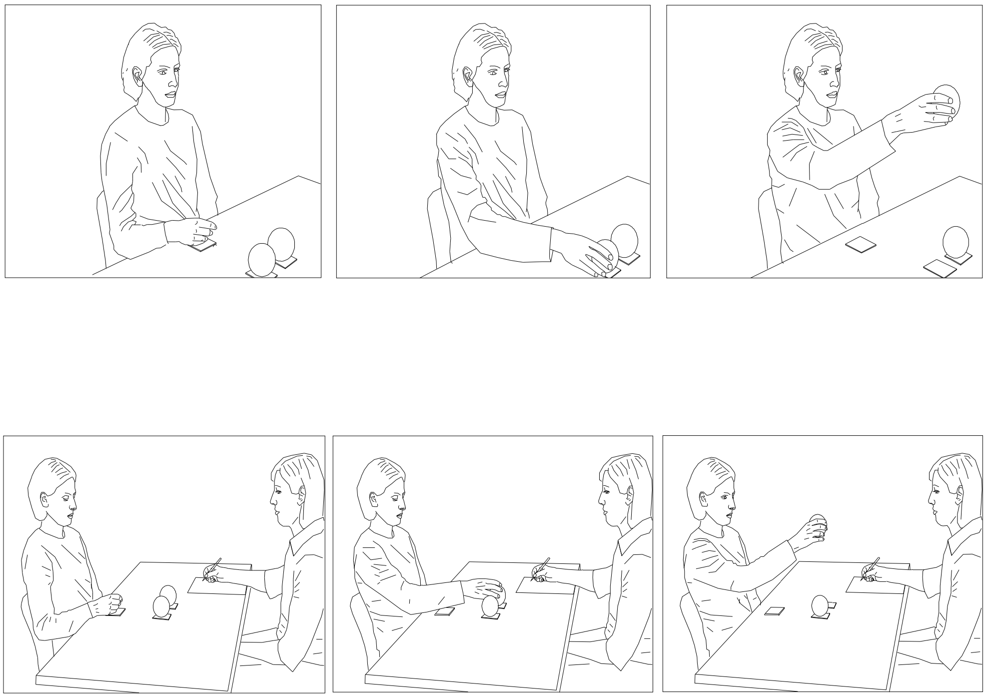


Figure 4.2 Panel 'a' depicts the sequence of events for the 'individual' condition. From left to right, the participant is resting her hand on a starting pad, and then she reaches towards, grasps and lifts the object. Panel 'b' depicts the sequence of events for the 'communicative' condition. From left to right, the participant is resting her hand on a starting pad, then she reaches towards, grasps and lifts the object on the basis of the chosen colour sequence as to communicate a specific word, then the co-experimenter writes on a paper sheet the deciphered word.

4.3 Results

Participants opened the hand as to reach maximum hand aperture faster for the communicative than for the individual condition [160 vs. 137 mm/s; $F_{(1,9)} = 5.9$; $p < .05$; see Figure 4.3a]. Further, the time of maximum trajectory height was reached earlier in communicative than individual conditions [461 vs. 504 ms; $F_{(1,9)} = 6.7$; $p < .05$; see Figure 4.3b].

In relative terms the maximum trajectory deviation was greater for the communicative than for the individual condition [48 vs. 54 %; $F_{(1,9)} = 6.7$; $p < .05$; see Figure 4.3c].

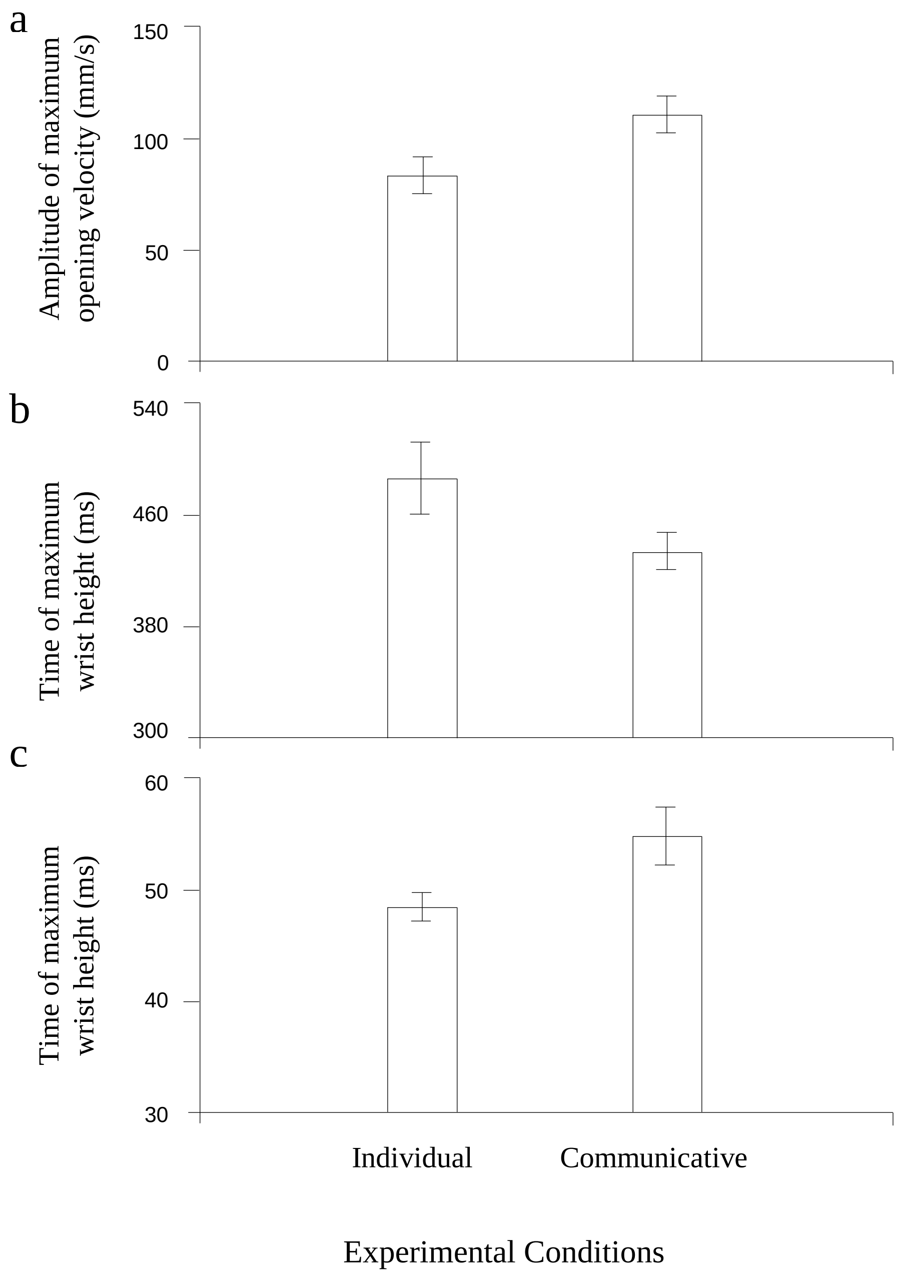


Figure 4.3 Graphical representation of the mean values for the ‘individual’ versus the ‘communicative’ conditions for the amplitude of maximum opening velocity (panel ‘a’), the time of maximum wrist height (panel ‘b’) and the maximum wrist deviation as a percentage of movement duration (panel ‘c’).

4.4 DISCUSSION

Differently from other species, for human beings the possibility to communicate is not confined to a limited number of signals. Every action can become a communicative signal. The only pre-requisite is to execute the action with a communicative intention.

What the present results reveal is that the imposition of a communicative intent is not neutral with respect to action kinematics: the intention to communicate alters the parameters of the movement. Therefore, the very same action – reach towards and grasp a sphere – is executed differently depending on whether it carries a communicative or a purely individual intent.

Previous studies have already shown that intention mechanism modulate actions kinematics (Ansuini et al., 2007; Becchio, Sartori, Bulgheroni, Castiello, 2008b; Castiello, 2003). For example, kinematics has been shown to be sensitive to prior intentions, i.e. to intentions formed in advance and representing the end-goal of the action (Searle, 1983). Ansuini and colleagues (2007) found that modulation of hand shape during reach-to-grasp takes into account the end-goal of the action in addition of object geometry. Specifically, hand shaping is different depending on whether the prior intention is to lift the object or insert it into a niche. Becchio and colleagues (2008b) demonstrated similar effects for social intentions, i.e. intentions directed towards another person. In this study, participants were requested to move an object from a location to another (individual intention condition) or to pass it to a partner (social intention condition). Different kinematics patterns were observed for “moving” actions and “passing” actions, suggesting that the same motor sequence can assume different features depending on the intention (individual vs. social) guiding its execution.

The present study extends our knowledge of intentional mechanism to a different and yet unexplored form of intentionality, i.e. communicative intentionality. Communicative intentions can be regarded as a special form of social intentions. What renders communicative intentions special is that they not only are directed towards another agent, but require, as part of their content, that the other agent recognizes the speaker’s intention to communicate (Grice, 1989). So conceived, communicative intentions (a) always occur in the context of a social interaction with a partner, (b) are overt, in the sense that they are intended to be recognized by the partner and (c) their satisfaction consists precisely in the fact that they are recognized by the partner.

By satisfying these requirements, the present experiment provides a first measure of the influence that communicative intentions exert on the level of action kinematics. In particular, three key parameters, the speed at which the hands opened, the maximum wrist trajectory height and deviation were found to be different for the communicative condition compared to the individual condition. A higher speed of fingers’ opening for the ‘communication’ condition may signify that when the task was to use the object as to communicate to another person, participants needed more time during the 'closing' phase as to compute a careful approach to the object. This is because the determination of the contact points for the fingers is crucial when the task implies showing the object to another person. In contrast, when the task is executed with a purely individual intention, the object can be grasped in whatever orientation without compromising the goal of the action. Similarly, anticipating the time at which the wrist trajectory reaches its peak and performing a more curved trajectory path allows for more time to prepare a suitable hand posture during a longer deceleration phase for the 'communication' condition.

An interesting aspect of these results concerns the lack of motor constraints. First, because the subsequent action was the same for both the communicative and the individual condition (lift the object), this rules out the possibility that differences in kinematics simply reflect differences in motor planning. Whereas such explanation may account for actions executed with different prior intention and thus followed by different actions (e.g. Ansuini et al., 2007), it does not apply to actions motivated by different intentions (communicative vs. individual) but followed by the same lifting action. Second and more importantly, because the object was hold by the agent and simply showed to the partner in the communicative condition, this eliminates the possibility that differences in kinematics reflect mere coordination constraints. Whereas passing an object requires adjusting one's action to the action of another individual (Becchio et al., 2008b; Meulenbroek, Bosga, Hulstijin & Miedl, 2007), communicating a meaning does not require any motor coordination with others. What is required is simply that the other person recognizes the communicative signal generated by the agents and attributes the correct meaning to it. Both in the individual and in the communicative condition, the motor sequence ended with the lifting of a sphere. The only difference is that in the communicative condition the action is intended to have a communicative effect on the partner, i.e. that the partner represents the meaning that the agents intends to communicate.

5. The influence of gender and race stereotype priming on social action[4]

Abstract

In two experiments the influence of gender and race on the kinematics of a pre-planned action performed in a social context was addressed. In both experiments participants were requested to reach towards, grasp a stimulus and place it either in a concave container (non-social condition) or in the hand of a partner (social condition). In Experiment 1 the partner could either be a female or a male individual. In Experiment 2 the partner could be either black or white. The results indicate that whereas race did not influence the kinematics of the reach-to- grasp movement, gender did bring to significant changes. In particular, participants displayed faster movements and specific kinematics when interacting with partners of the opposite sex. We contend that these results reflect how gender stereotypes affect the motor aspects of social interaction.

[4] Kuria, E. N., Sartori, L., Castiello, U., & Rumiati, R. I. (*under revision*). The influence of gender and race stereotype priming on social action. *Consciousness and Cognition*.

5.1 INTRODUCTION

Mechanisms relevant for skilful social interactions have been regularly addressed by psychologists. In this respect, recent evidence suggests that social intentions translate into specific motor patterns that echo the actor's attitudes. For instance, Georgiou and colleagues (2007) demonstrated that social context and intentions have the capacity to shape the kinematics of reach-to-grasp movements. Grasping an object with the intent to cooperate with a partner elicits a kinematic patterning which differs from that observed when the same object is grasped with no intention to cooperate. On a similar vein, Becchio and colleagues (2008a; 2008b) demonstrated that actions performed in isolation are different from those aimed at a subsequent social interaction. For the social task, participants were asked to place an object in a partner's hand (social condition), or to place the object in a container (non-social condition). Results revealed specific patterns of spatial trajectories for single intended actions and social intended actions suggesting that planning incorporates overarching social goals into the action plan.

Additionally, evidence from primate studies indicates that the motor cortex is directly involved in social cognition. Fuji, Hihara and Iriki (2007) recorded the neuronal activity of two male Japanese macaques simultaneously from the Premotor (PM) and the parietal cortices of the left hemisphere while the monkeys performed a food grabbing task in a shared social space. A subpopulation of motor responsive neurons corresponding to the other's action was found in the PM and parietal cortices. PM neurons were found to be significantly activated for self than for other's action, whereas parietal neurons were more active during resolution of social conflicts. The authors proposed that the differences observed in arm movements during the reach-grabbing task were a result of the changes in social context, and hence that the movements themselves contained contextually different information that could contribute a significant role in social action cognition.

Altogether these results suggest that the reach-to-grasp paradigm is a reliable measure for testing social attitudes in motor control. Importantly, they suggest that whereas moving an object realizes individual intention, sharing a common social space during action or passing an object to another person necessarily involves social intention.

An aspect which has yet to be investigated in terms of social action concerns the influence that social dimensions such as gender and race might have on motor processes. For instance, according to models of cooperation and competition, attitudes harboured by males and females seem to shape their performance (Gneezy, Niederle and Rustichini, 2003; Van Vugt, De Cremer and Janssen, 2007) even at an early age (Gneezy and Rustichini, 2004). Gneezy and colleagues (2003) showed that women's competitiveness is hinged on the gender of their counterparts, i.e. competing against men, women cooperated, but were competitive towards other women under the same conditions. Moreover, interacting with partners of different racial backgrounds has been found to elicit differential behavioural performance. Goff, Steel and Davis (2008), for example, showed that during interracial interactions, the fear of being stereotyped as racially prejudiced by a black conversation partner led white individuals to distance themselves from their partner; the fear of being labelled prejudiced led to racial distancing.

Existing behavioural data (as mentioned above) neatly ties to results obtained from imaging studies in humans. Phelps and colleagues (2000), in addition to replicating the behavioural findings previously obtained by others (Cunningham, Preacher & Banaji, 2001; Dasgupta, McGhee, Greenwald & Banaji, 2000; Greenwald, McGhee & Schwartz, 1998), also found a correlation between implicit measures of race biases, assessed by using the Implicit Association Test (IAT, Greenwald et al., 1998) and the startle reflex, resulting to an activation of the amygdala in White American participants. Furthermore, Knuston, Mah, Manly, & Grafman (2007) have identified brain areas that correlated with beliefs about gender and race, and suppression of those attitudes using the IAT performed during magnetic resonance imaging (MRI) scanning. Results implicated the right medial frontal gyrus and the right superior frontal gyrus as underlying these beliefs, whereas the left middle frontal gyrus was found to be activated when they were suppressed. Another imaging study has revealed that the activation in brain areas related to face-identification and recognition were influenced by racial group membership (Golby, Gabrieli, Chiao & Eberhardt, 2001). It was shown that both black and white participants were better at recognizing individuals of their own race than those of other races, and a greater activation in the fusiform face area (FFA) for faces of the subjects' own race was observed.

Given these premises, here we investigated whether the kinematics of a reach to grasp movement performed with the intent to pass an object to a partner (social condition) vary depending on the gender and/or race of the partner. As outlined above, recent developments in the investigation of how gender and race influence social relationships make this a timely and tractable issue.

5.2 Experiment I - Gender stereotype priming

In this experiment participants were requested to reach for, grasp, lift a target object and either put it in a container or pass it to a confederate. On 50% of the trials, the confederate was of the same gender as the acting participants, whereas in the remaining 50% was of a different gender. We reasoned that if women when interacting with men show a tendency to cooperate, but to compete when interacting with other women, then the motor control system should be more alerted and differences in terms of speed should be evident. Conversely, since males show no significant differences in competitive attitudes while interacting with either sex, no significant alterations were expected in the motor control system during action execution towards females. Specific predictions in the sort of readjustments that might be expected to occur and the dependent measures which should be sensitive to the social manipulation are reported below (see 'Data analysis' section).

5.2.1 Method

5.2.1.1 Participants

Fifteen students, 8 women and 7 men (mean age = 24.7 years, SD = 3.8), took part in the experiment.

5.2.1.2 Stimulus

The stimulus was an egg-shaped object located in front of the participant at a distance of 25 cm from the hand starting position along the midsagittal plane.

5.2.1.3 Procedure

The two tasks for the participants consisted of reaching towards, grasp, lift the stimulus and (i) place it either on a small round platform (12 cm diameter) positioned on the end-pad located at his/her right side, or (ii) placing it within a confederate's hand. The confederate was a co-experimenter of the same or different gender that the participant. There were three experimental conditions:

- Non-Social Condition. Each participant was requested to reach towards the stimulus, grasp it and place it within the round platform.
- Social Condition – same gender. Each participant was requested to reach towards the stimulus, grasp it and place it

within the confederate's hand. The confederate was of the same gender as the participant, either female or male.

- Social Condition – different gender. Each participant was requested to reach towards the stimulus, grasp it and place it within the confederate's hand. The confederate was of a different gender than the participant.

For all conditions participants were requested to start the action after a tone (880 Hz/200 ms) was presented. The order of conditions and trials was randomized across participants. For each condition, each participant performed 30 trials (90 trials in total).

5.2.1.4 Data Analysis

Temporal data was normalized (as a percentage of movement duration) in order to avoid possible differences due to possible differences in movement speed between females and males participants. Because our hypotheses focused on the degree of competitiveness which might be triggered by performing an action in the presence of a confederate of a similar or different gender, we confined our analyses on 'speed' measures which, as previously demonstrated, might better exemplify the degree of competitiveness (Georgiou et al., 2007). Therefore we considered the time and amplitude of maximum peak velocity for the reaching component and the time and amplitude of maximum speed of fingers' opening for the grasping component.

The movement sequence of each participant was segmented in two action steps: (a) reach towards and grasp the stimulus, (b) lifting the stimulus and transporting it to the required position. Data analysis focused on the first movement phase. This is because this phase was common in all experimental conditions, and possible differences (if any) in social intention should be already evident during this movement phase as previously demonstrated (Becchio et al., 2008a; 2008b). The means for each of the considered kinematic parameters were entered into a mixed analysis of variance (ANOVA) with experimental condition (non-social, social-same gender, social-different gender) as a within-subjects factor and participants' gender (male, female) as a between-subjects factor. Post-hoc comparisons were carried out using simple effects (Bonferroni corrected, alpha level = $p < .05$).

5.2.1.5 Results

The interaction between experimental condition and participants' gender was significant for the amplitude of maximum peak wrist velocity [$F_{(2,26)} = 3.4$, $p < .05$] and for the time at which the maximum velocity of finger opening was reached in both absolute [$F_{(2,26)} = 5.9$, $p < .05$] and relative [$F_{(2,26)} = 3.1$, $p < .05$] terms. As shown in Figure 6.1a, for males participants' when the action towards the target object implied a social interaction with a partner of a different gender the amplitude of maximum peak velocity was lower than when the action towards the target object implied a social interaction with a partner of the same gender and for the non-social condition [$p_s < .05$]. Similarly for female participants, the maximum amplitude of peak velocity was lower when interacting with a confederate of a different gender, than when interacting with a confederate of the same gender and during the non-social condition [$p_s < .05$]. With respect to the time at which the peak velocity of fingers opening was reached (see Figure 6.1b), males reached this peak later for different than for the same gender condition and the non-social conditions [$p_s < .05$; see Figure 6.1b]. Females exhibited no significant differences when comparing this measure for the same and different gender condition, although the peak velocity of finger opening was reached later for the non-social than for the same and different gender conditions.

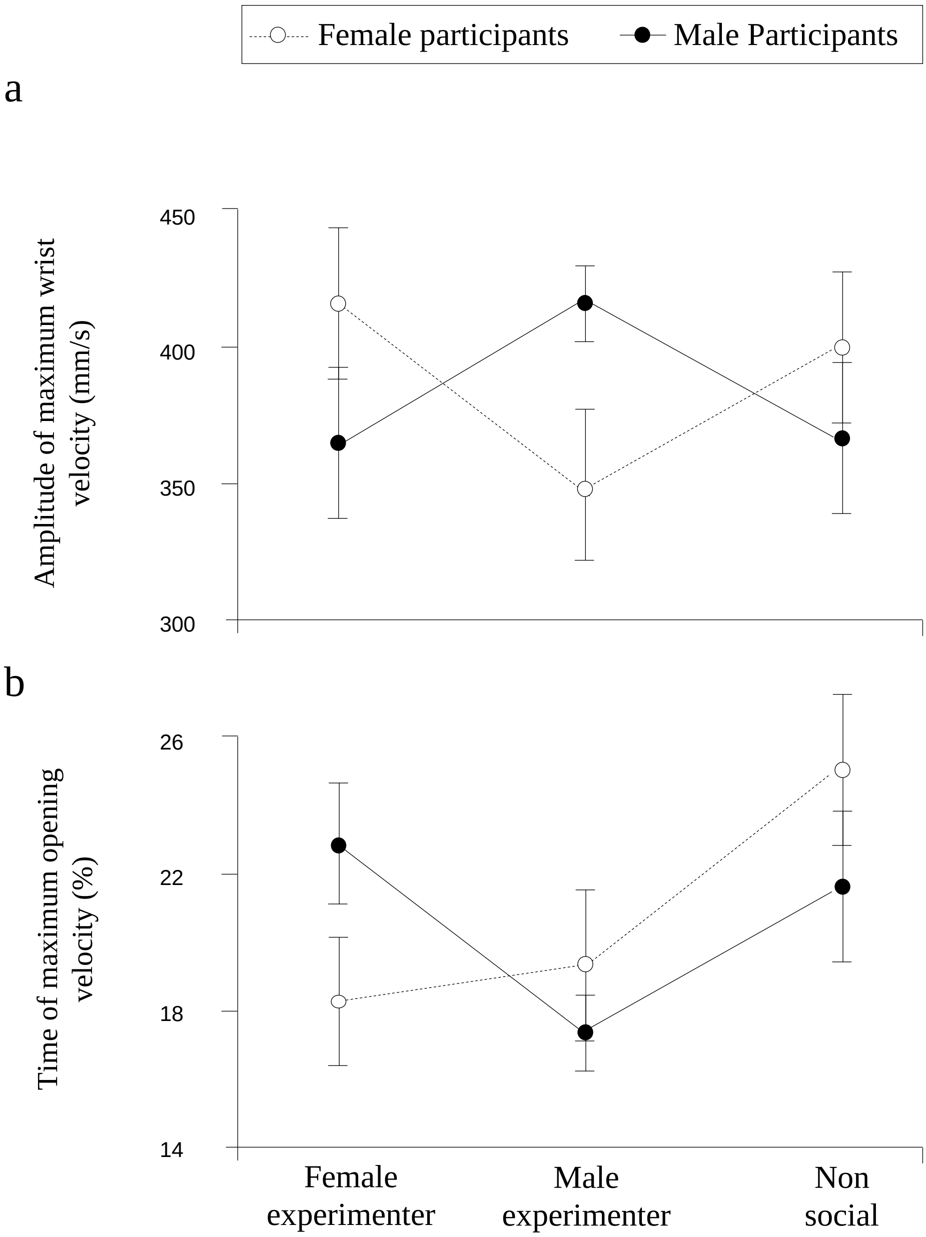


Figure 5.1 Effect of gender on the reaching component (panel 'a'). The graph shows that the amplitude of peak velocity was higher for the opposite-sex interactions, compared with the same-sex interactions. Differences in the non-social condition between genders were not significant. Effect of gender on the grasping component (panel 'b'). The time at which maximum hand-opening speed was achieved (as a percentage of movement duration) was earlier for male participants when interacting with a partner of the same sex, whereas for females it remained invariant with respect to the partner's gender. Bars represent the standard error of means.

5.3 Experiment II – Race stereotype priming

In this experiment we used the same paradigm adopted in Experiment 1 to investigate whether the "race" dimension has the ability to manipulate behaviour during social interactions. Participants interacted with a confederate belonging either to the same or to a different race. If race had the salient property of altering behaviour as in racial distancing during interracial interactions, then we expected the motor system to be sensitive in detecting changing attitudes during such interactions. Because of the effects of gender on kinematics reported in Experiment 1, here the 'gender' factor was also considered.

5.3.1 Method

5.3.1.1 Participants

Twenty-nine students: 12 women (7 white) and 17 men (10 white), mean age = 23.7 years, SD = 3.3, took part in the experiment.

5.3.1.2 Stimulus

The stimulus was an egg-shaped object located in front of the participant at a distance of 25 cm from the hand starting position along the midsagittal plane.

5.3.1.3 Procedure

Procedures were the same as for Experiment 1 except that the variables manipulated under the social context were both the gender and the race of the experimenter. This brought to four experimental conditions:

- Social Condition – same race, same gender. The experimenter was of the same gender and race as the participant.
- Social Condition – same race, different gender. The experimenter was of the race as the participant, but of a different gender.
- Social Condition – different race, same gender. The experimenter was of a different race from the participant, but of the same gender.
- Social Condition – different race, different gender. The experimenter was of a different race and gender from the participant.

The order of conditions and trials was randomized across participants. For each condition, participants performed 30 trials (120 trials in total). Further, an indirect assessment of racial evaluation i.e. the Implicit Association Test (IAT) was also administered to the participants after the grasping task. Participants were asked to categorize Black or White faces, while simultaneously categorizing words as good (joy, love, peace, wonderful, pleasure, glorious, laughter) or bad (agony, terrible, horrible, nasty, evil, awful, failure, hurt). For half of the trials, subjects were asked to press a right button if the stimulus was either a White face or a good word and a left button if the stimulus was either a Black face or a bad word. For the remaining half of the trials, the pairings were reversed. The two conditions were counterbalanced. The difference in speed to respond to the Black + good/White + bad pairings compared to the Black + bad/White + good pairings provided the indirect measure of group evaluation. The results were automatically generated and graded as either no/ weak/moderate or strong preference for white faces.

5.3.1.4 Data Analysis

The means for each of the considered kinematic parameters were entered into a mixed analysis of variance (ANOVA) with experimental condition (non-social, social) as a within subjects factor and gender (male, female) and race (black, white) as between-subjects factors.

5.3.1.5 Results

5.3.1.5.1 Kinematics

The main factor race did not interact significantly with both the ‘experimental condition’ and the ‘gender’ factor. However, the gender-effect on grasping observed in study 1 was replicated. The interaction between experimental condition and participants’ gender was significant for the amplitude of maximum peak wrist velocity [$F_{(1,28)} = 5.8$, $p < .05$]. The pattern of results mirrors that already reported for Experiment 1.

5.3.1.5.2 Implicit Association Test (IAT)

Consistent with previous findings in the implicit evaluation of race preferences, European subjects showed a strong pro-white bias: 5% of the white subjects preferred Blacks, 20% had no preference, whereas 75% were pro-white. African subjects likewise showed a strong liking for whites over blacks, but their results were more varied: 11.76% preferred blacks, 17.65% showed no preference, whereas 70.58% were pro-white.

5.4 DISCUSSION

The aim of the present study was to investigate whether social dimensions such as gender and race influence the kinematics underlying a social action. Our results indicate that gender influences how an object is approached when the intent is to interact with a confederate. In contrast race appears to have no influence in such function. In terms of gender it was found that both females and males were faster in approaching the object when the confederate was of the same than of a different gender. These results may be interpreted as evidence of the influence of gender driven prior intention on kinematics. If we consider the reach-to grasp action, two components of intention might be identified. One component, intention-in-action, is concerned with the intention to reach and grasp for an object. Another component, prior intention, might be concerned with whom I am interacting with. Here we demonstrate for the first time that 'gender-driven' prior intentions are reflected in the kinematics, so that actions embedded in different social contexts, triggered by different 'gender-driven' prior intentions, show different kinematic characteristics. In this interpretation, reach-to-grasp actions executed within the 'same gender' context determine a pattern which resembles a competitive task. This is in accordance to recent models concerned with how attitudes harboured by males and females seem to shape their performance (Gneezy et al., 2003; Van Vugt, De Cremer & Janssen, 2007). In this view competitiveness seems to be centred on the gender of their counterparts. For instance, when interacting against men, women tend to cooperate, but when interacting against women they tend to compete.

When considering the pattern of results obtained for the grasping component it is of some interest that whereas males reach the peak of maximum speed of finger opening later when interacting with a confederate of a same gender, females reached this peak at a similar time when interacting with both the males and the female confederate.

The fact that fast reaching is accompanied by an earlier hand-opening is a well-established result (Wing, Turton and Fraser, 1986; Wallace & Weeks, 1988; Rand, Squire & Stelmach, 2006).

Specifically, the anticipation of the time at which maximum aperture between the thumb and index finger is achieved during a fast reach has been interpreted as a compensatory/safety mechanism. Anticipating this time allows for a longer 'homing' phase, an increased safety margin as to position the fingers on the object successfully. In our study, the fact that males participants reached the maximum peak of fingers' opening velocity earlier when producing the fastest reach (same gender condition) suggest a natural reorganization of the grasping component in light of the speed adopted at reaching level. That is, the anticipation of the peak of maximum fingers opening may indicate the need to reach an earlier maximum aperture. In this respect females seem to adopt a different strategy. What can account for these differences between gender groups?

Zajonc (1965) posited that the presence of one or more observers (audience effect) affects task performance by either enhancing it, or inhibiting it. Consistent with this theory, high arousal is experienced by people when they perform an action in front of others (Platania & Moran, 2001), even when the confederate present is passive and doesn't talk to the subjects (Guerin, 2001). Other studies have shown that males and females are affected differently by the presence of different sex audiences. In Corston and Colman (1996), for instance, when performing a computer-based tracking task in different audience conditions, male subjects showed a facilitator effect in the presence of a female audience, whereas females showed an inhibitory effect in the presence of a male audience. Social inhibition in females is not new to gender studies. It has been observed, for instance, that females perform poorer in mathematics as a function of the number of males in the room (Inzlicht & Ben-Zeev, 2000; Murphy, Steele & Gross, 2007). Corston and Colman (1996) maintained that the presence of males produces anxious feelings in females. It might be that these anxious feelings produce the social inhibition that in turn impairs performance. These anxious feelings could be attributed to "stereotype threat"; the phenomenon whereby individuals perform more poorly on a task when a relevant stereotype or stigmatized social identity is made salient in the performance situation" (Schmader & Johns, 2003). It is possible that in our experiment the mere presence of males triggered stereotype-related attitudes regarding male/female competence, thus inhibiting the unfolding of a natural kinematics which considers the coordination of the reaching and grasping components.

In contrast to the effects dictated by gender, the category "race" did not affect movement kinematics. This is surprising given that, as previously demonstrated, even subliminally presented faces activate racial stereotypes (Devine, 1989), although Bargh (1997) argued that the determining factor as to whether a stereotype is automatically activated is the frequency with which it has been stimulated in the past in the relevant social group. Several studies using the IAT have shown a negative evaluation of Blacks among White Americans in the form of faster responding in the Black +bad/White +good pairings (Greenwald et al., 1998; Dasgupta et al., 2000; Cunningham et. al., 2001). A discrepancy between pro-Black beliefs and attitudes as measured by direct self-report, and anti-Black, pro-White bias as assessed by indirect measures (IAT) is consistent with other studies with White American participants (Phelps et al., 2000; Dasgupta et al., 2000; Greenwald et al., 1998). In our study, the grasping task during social interaction in a race-modulated setting could have alerted participants into behaving in a socially acceptable manner towards members of a different racial group, making the grasping task more similar to direct self-reporting. The IAT however revealed pro-white bias in all subjects, a pattern that was not detected by the grasping task. The IAT could reflect attitudes, learned through experience in a culture that does not regard Blacks highly. It is likely that that over the years humans have learned to inhibit negative behaviour towards minority social groups, when this behaviour is considered unethical, despite harbouring negative attitudes towards them.

6. Both your intention and mine are reflected in the kinematics of my reach-to-grasp movement[5]

Abstract

The aim of the present study is to ascertain whether in a social context the kinematic parameters are influenced by the stance of the participants. In particular, we consider two basic modes of social cognition, namely cooperation and competition. Naïve subjects were asked either to cooperate or to compete with a partner (a professional female actor), whose attitude could be either congruent or incongruent with the task instructions. Thus, on congruent conditions, subjects cooperated or competed with a partner showing a congruent cooperative or competitive attitude. On incongruent trials, the partner assumed an attitude that was manifestly in contrast with the instruction: competitive for the cooperative task, cooperative for the competitive task. We hypothesized that this mismatch between partner's attitude and instruction would produce a sort of unexpected social situation, affecting the kinematics of

[5] *Published*: Becchio C., Sartori L., Bulgheroni M., Castiello U. (2008). Both your intention and mine are reflected in the kinematics of my reach-to-grasp movement. Cognition, 106, 894-912.

reach-to-grasp movement performed by the agents. If cooperative and competitive kinematic patterns are sensitive to the partner's attitude, then we should expect that an incongruent attitude have the potency to determine a reversal in kinematic patterning. Results revealed that for the incongruent trials the specific kinematic patterns for cooperation and competition found for the congruent conditions where modified according to the incongruent attitude assumed by the model actor. We suggest that this 'attitude' contagion is part of a sophisticated system that allows us to infer about the intention to act in a social context.

6.1 INTRODUCTION

It's a commonplace to say that human beings are social.

In the previous study we have demonstrated the existence of different kinematical patterns for single independent action and actions preparing to a subsequent social interaction. If intentions shape kinematics – as we have shown – mirroring an action may enable the observer to represent the agent's social intentions. In contrast to isolation models predicting no differences between actions having the same goal, results revealed how the planning and execution of an action are modulated with respect to the intention of the agent. The adoption of a particular intention (individual vs. social, cooperative vs. competitive) translates into a measurable kinematical pattern, which even in the planning phase (reach to grasp for an object) is different from the kinematical pattern of the same action motivated by a different intention. Prior to the interaction, the agent's intention to act cooperatively versus competitively shapes the kinematics of the action. The previous study focused on the agent's intention, whereas in the present study we focused on the attitude of the partner. Is the kinematics of the action influenced by the attitude displayed by the partner? To this end, we included an experimental manipulation intended to create a mismatch between task instructions and partner's attitude. We analysed the kinematics of the very same action – reach and grasp for a wooden block – in two different contexts provided by a cooperative and a competitive task. For the cooperation task, participants assigned in pairs were required to reach and grasp for their respective object and to cooperate as to form a tower by putting one object on the top of the other in the middle of the working surface. The competition task was similar to the cooperation task except that participants had to compete as to put their object in the middle of the working surface first. Suppose an agent is asked to cooperate with a partner clearly displaying a competitive attitude. Will the partner's attitude influence the action of the agent?

6.2 Method

6.2.1 Participants

Twelve participants (6 females - 6 males, ages 19–35) took part in the experiment. A professional female actor (34 years of age) took part in the experiment and acted as a partner in conditions 5-12 as outlined below.

6.2.2 Stimuli

The stimuli were a pair of blue wooden blocks (4 x 4 x 8 cm). The blocks were placed in the middle of the working surface at a distance of 18 cm away between them and 21 cm away from the hand starting position (see Figure 5.1a). A vertical line was drawn in the centre of the table, to guide each participant when moving their respective object to the middle of the table (see Figure 5.1a).

6.2.3 Procedures

Participants were requested to start the action after a tone (880Hz/200 ms) was presented. For cooperation and competition tasks, two participants (a naïve participant and a professional actor) were seated opposite to each other. Naïve participants believed that the actor was just another participant. They were required to reach and grasp for their respective objects (Figure 5.1b) and to either cooperate so as to form a tower by putting one object on top of the other (see Figure 5.1c), or compete to be the first to place their object on the bottom (see Figure 5.1d).

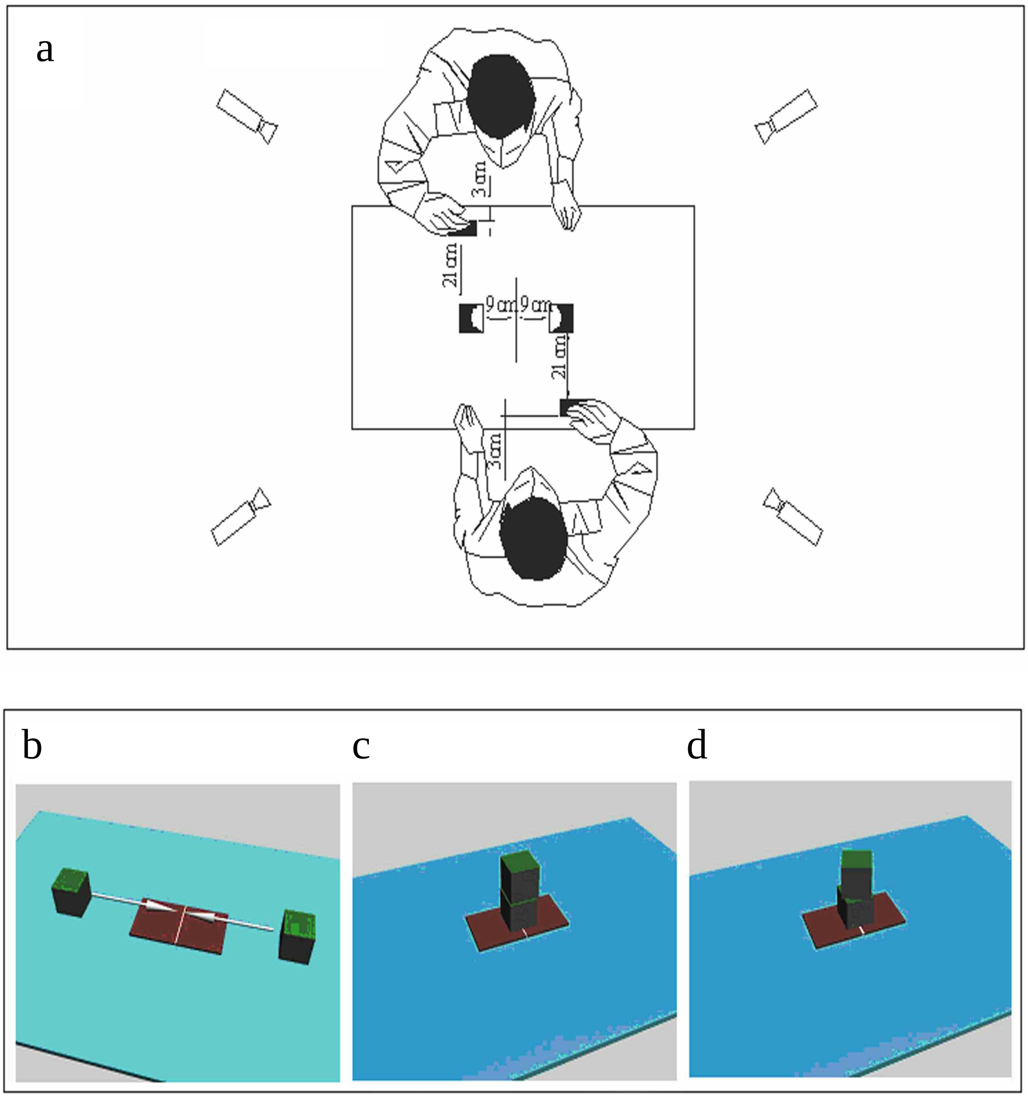


Figure 6.1 Experimental set up. Panel 'a' represents the participants' posture, the positioning of the stimuli and the positioning of the infrared cameras. Panel 'b' represents the direction of movement. Panels 'c' and 'd' represent the cooperation task and competition task, respectively. Note that for the 'cooperation bottom' task the object is brought in the middle of the table, whereas in the 'cooperation top' task the object is brought on top of another object in the middle of the table. Conversely, in the competition task participants compete to put their object in the bottom of the tower first (middle of the table).

Participants were tested in 12 experimental conditions:

1. Single-agent: Natural speed bottom. In this condition, each participant was required to reach and grasp at a natural speed the stimulus positioned in front of his/her right hand and bring it in the middle of the working surface.
2. Single-agent: Natural speed top. In this condition, each participant was required to reach and grasp at a natural speed the stimulus positioned in front of his/her right hand and put it on top of an object previously placed in the middle of the working surface.
3. Single-agent: Fast speed bottom. In this condition, each participant was required to reach and grasp as fast as possible the stimulus positioned in front of his/her right hand and bring it fast in the middle of the working surface.
4. Single-agent: Fast speed top. In this condition, each participant was required to reach and grasp as fast as possible the stimulus positioned in front of his/her right hand and put it fast on top of an object previously placed in the middle of the working surface.
5. Passive Observer: Natural speed bottom. This condition was similar to the natural speed bottom - single agent condition except that each participant performed the action in the presence of another person (one of the experimenters observing the scene).

6. Passive observer: Natural speed top. This condition was similar to the natural speed top - single agent condition except that each participant performed the action in the presence of another person observing the scene.
7. Passive observer: Fast speed bottom. This condition was similar to the fast speed bottom – single agent condition except that each participant performed the action in the presence of another person observing the scene.
8. Passive observer: Fast speed top. This condition was similar to the fast speed top – single agent condition except that each participant performed the action in the presence of another person observing the scene.
9. Congruent cooperation bottom/top condition. The two agents (a naïve participant and the actor) seated opposite to each other and were required to reach for their respective objects. One agent was instructed to put it on the bottom whereas the other agent was instructed to put it on the top so as to form a tower (see Figure 5.1c). The top/bottom order was counterbalanced across agents. In this condition, the actor assumed an attitude in line with the 'cooperation' instructions.
10. Incongruent cooperation bottom/top condition. The two agents seated opposite to each other and were required to reach for their respective objects. One agent was instructed to put it on the bottom whereas the other one was instructed to

put it on the top to form a tower (interaction phase, see Figure 5.1c). The top/bottom order was counterbalanced across agents. In this condition the actor was covertly signalled by the experimenter to assume a 'competitive' attitude (facial expression and body posture) during the reach-to-grasp phase. To signal the actor as to assume an incongruent attitude, the experimenter pretended to adjust the stimuli on the working surface and touched the actor slightly on the back. This operation (without the back touch) was performed various times for both the congruent and incongruent conditions and from both the naïve and the actor model's side as to avoid that the naïve participant would associate this operation with the incongruent attitude. During the interaction phase, the actor cooperated with the partner as requested by the instructions

11. Congruent competition condition. This condition was similar to the cooperation condition except that agents had to compete as to put first the respective object in the bottom of the tower (see Figure 5.1d). In this condition the actor assumed an attitude in line with the 'cooperation' instructions.
12. Incongruent competition condition. This condition was similar to the cooperation condition except that agents had to compete as to put first the respective object in the bottom of the tower (see Figure 5.1d). In this condition, the actor was

covertly signalled (as reported above) by the experimenter to assume a 'cooperative' attitude during the reach-to-grasp phase. During the interaction phase, the actor cooperated with the partner as requested by the instructions.

Participants performed 10 trials for experimental conditions 1-8 in separate blocks. For both the cooperation and competition conditions the congruent and the incongruent trials were intermingled within a 100 trials block. In particular, the incongruent trials occurred only 20% of the total number of trials as to avoid predictive effects. This brought to 80 congruent trials (40 for cooperation and 40 for competition) and 20 incongruent trials (10 for cooperation and 10 for competition). Because of the different number of trials between congruent and incongruent trials, we randomly chose for subsequent analyses 20 congruent trials (10 for cooperation and 10 for competition) out of the 80 congruent acquired trials.

6.2.4 Data Analysis

Kinematic analyses were restricted to the phase leading up to the grasping of the object. This is because this phase was common to all experimental conditions. In the single agent condition, this movement preceded the individual action of placing the object on the table, whereas in the cooperative and the competitive task it was preparatory to the successive social interaction (interaction phase), being not part of the interaction itself.

The means for each kinematical parameter of interest obtained for the 12 experimental conditions were determined for each participant. We performed a series of one-way preliminary analyses of variance (ANOVA) on the measures of interest as to confirm the results obtained in a previous experiment (Georgiou et al., 2007). These analyses were carried on both the naïve group of participants and the actor. The reason for carrying out such analyses was twofold. First, if the results of the preliminary analyses would confirm those obtained in the previous study, then we could concentrate our analyses on the four condition of interest for the present study (Conditions 9-12). Second, for the sake of brevity, we would avoid reporting already known data which are tangential to the scope of the present work. These preliminary analyses checked for: (a) top/bottom differences for each kinematical parameter for each condition; (b) differences between natural slow movements performed alone and natural slow movements performed in the presence of a passive observer; (c) differences between fast movements performed alone and fast movements performed in the presence of a passive observer; (d) differences between natural slow movements performed in the presence of another person and the cooperative movements (which were performed quite naturally and slower); (e) differences between fast movements performed in the presence of another person and the competition movements (which were performed fast); (f) differences between the cooperative and the competitive movements.

In line with previous findings (Georgiou et al., 2007), we found that for the dependent measures of interest there were no top/bottom differences, no differences between 'slow' and 'fast' movements performed alone or in the presence of a passive observer and large differences between cooperation and competition (see Appendix IV). Importantly there were differences within key kinematical landmarks between the cooperative movements and the 'slow' movements performed in the presence of a passive observer and between the competitive movements and the fast movements performed in the presence of a passive observer (see Appendix IV). This signifies that cooperative and competitive actions have clear and distinct kinematic patterns. For instance, movement duration was shorter and amplitude of peak velocity was higher for 'competitive' than for 'fast' movements performed alone. Conversely, movement duration was slower and the amplitude of peak velocity was lower for 'cooperative' than for 'slow' movements performed alone. These findings applied to both the actor and the naïve group of participants. Consequently, top/bottom data were collapsed as well as those for natural and fast movements performed in the presence or absence of a passive observer. Subsequently we run an ANOVA with type of task (cooperation, competition) and type of trial (congruent, incongruent) as within-subject factors as to specifically test the hypothesis that independently from the overarching goal of the task (cooperate or compete) the incongruent social attitude assumed by the actor may bias the action of the naïve agent cooperating or competing with her. The same analysis was performed for the actor kinematics.

Correlation analyses were conducted to explore whether there was a linear relationship within the movements of the actor and the naïve participants for the congruent and incongruent competitive and cooperative conditions. In particular, we investigated the existence of such relationship for three key kinematical parameters using Pearson product-movement correlation coefficient: time to peak velocity, maximum peak height trajectory and time of maximum grip aperture. These parameters were chosen because they might allow inferring the degree of cross-talk between the two agents during the social action. In line with previous findings, we expected significant correlation for these parameters for the cooperative congruent condition, but no significant correlation for the competition congruent condition (Georgiou et al., 2007). Further, in line with the hypothesis that the experimental manipulation would affect the agent's kinematics, we expected no significant correlation for the incongruent cooperation conditions.

6.3 RESULTS

As previously demonstrated the reach-to-grasp action performed during a cooperation task showed a longer movement duration, a lower amplitude peak velocity, a higher maximum height of the wrist trajectory, a later time of maximum grip aperture and a smaller amplitude of grip aperture than a reach-to-grasp action performed during a competitive task (Georgiou et al., 2007). Furthermore, whereas significant correlations emerged when comparing key kinematics landmark during the cooperation task, no significant correlations for the same measures were evident for the competitive task (Georgiou et al., 2007). With this is mind, the following sections report the effect of the incongruent social attitude on these well-established patterns.

6.3.1 Actor Model Kinematics

The interaction type of task by type of trial was significant for movement duration [$F_{(1,9)} = 224.8$, $p < .001$], wrist peak velocity [$F_{(1,9)} = 79.8$, $p < .001$], amplitude of the maximum height of the wrist trajectory from the working surface [$F_{(1,9)} = 96.1$, $p < .001$], time to maximum grip aperture [$F_{(1,9)} = 145.7$, $p < .001$] and the amplitude of maximum grip aperture [$F_{(1,9)} = 191.5$, $p < .001$]. Post-hoc contrasts [$p_s < .05$] revealed that, for the competition tasks, movement duration was longer for the incongruent than for the congruent condition (677 vs. 621 ms). For the reaching component, the amplitude of wrist peak velocity was lower (676 vs. 714 mm/s) and the height of the trajectory wrist was higher (70 vs. 64 mm) for the incongruent than for the congruent condition. For the grasping component, the time of maximum grip aperture was later (56 vs. 47 %) and the amplitude of maximum grip aperture was smaller (84 vs. 92 mm) for the incongruent than for the congruent condition.

The same influence of the assumed social attitude on movement kinematics was evident when comparing the action performed by the actor model in the congruent and incongruent cooperative condition. For example, movement duration was shorter (657 vs. 737 ms) wrist peak velocity was higher (714 vs. 675 mm/s) and the amplitude of the maximum height of the wrist trajectory from the working surface was lower (64 vs. 70 mm) for the incongruent than for the congruent condition. For the grasping component, time and amplitude of maximum grip aperture were earlier (47 vs. 55 %) and wider (91 vs. 84 mm) for the incongruent than for the congruent condition.

These results suggest that although the actor model was instructed to maintain the action pattern congruent with the task (competition or cooperation), kinematic features for the incongruent task emerged. This signifies that, independently from the instruction, assuming a certain attitude brought to a pattern of movement related to the assumed social attitude.

6.3.2 Naïve Participant Kinematics

The interaction type of task by type of trials was significant for movement duration [$F_{(1, 119)}$ = 624. 1, p < .001], the amplitude of wrist peak velocity [$F_{(1, 119)}$ = 654.1, p < .001], the amplitude of the maximum height of the wrist trajectory from the working surface [$F_{(1, 119)}$ = 439. 5, p < .001], the time of maximum grip aperture [F(1,

119) = 412, $p < .001$] and the amplitude of maximum grip aperture [$F_{(1, 119)} = 1779.7$, $p < .001$].

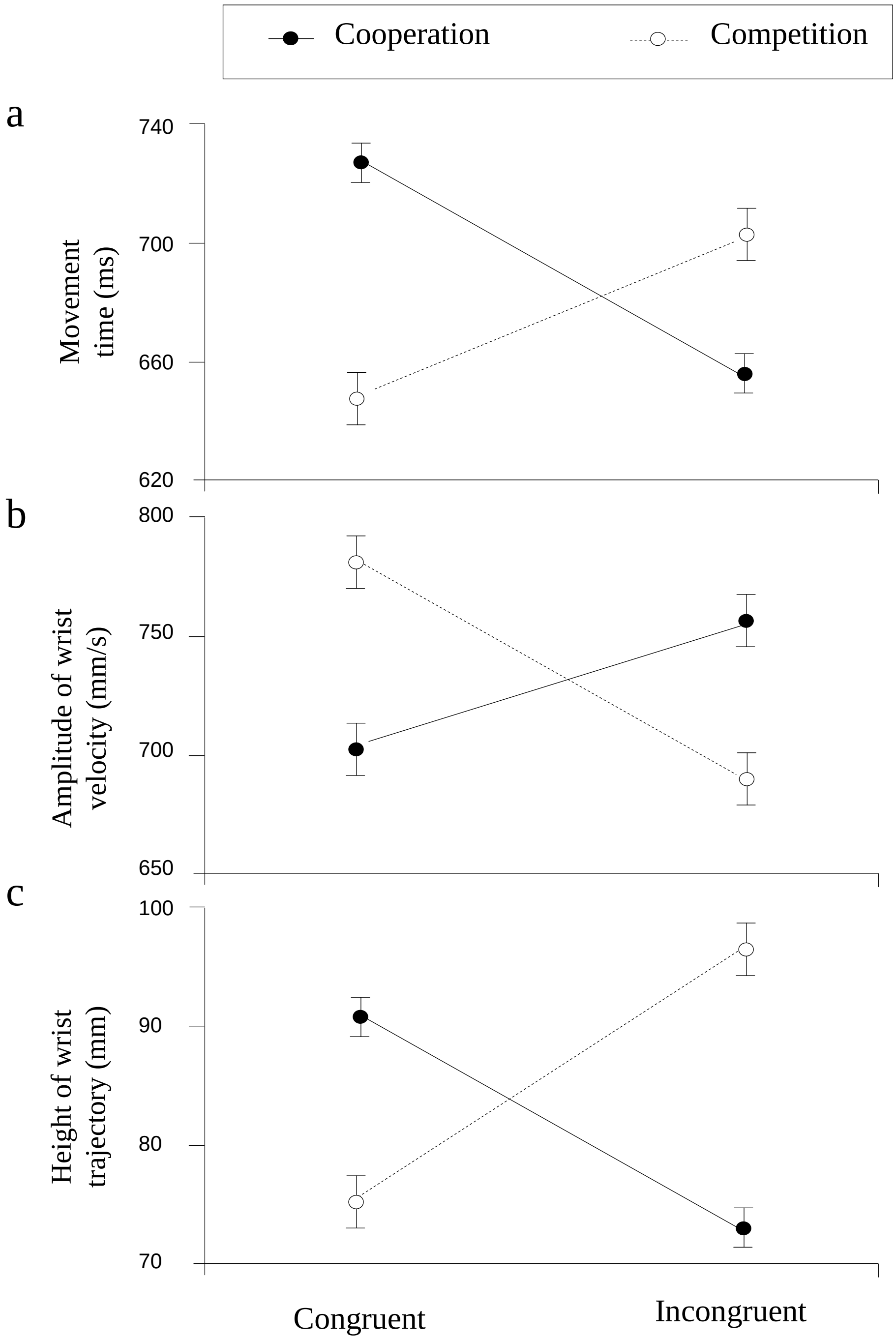


Figure 6.2 Graphical representation for the interaction type of task by type of trial for movement duration (Panel 'a'), amplitude of wrist velocity (Panel 'b') and height of wrist trajectory (Panel 'c').

Post-hoc contrasts [$p_s < .05$] revealed that, for the competition tasks, movement duration was longer for the incongruent than for the congruent condition (see Figure 6.2a). For the reaching component, amplitude of wrist peak velocity was lower (see Figure 6.2b), and height of the trajectory wrist was higher (see Figure 6.2c) for the incongruent than for the congruent competition condition.

For the grasping component, time of maximum grip aperture was later (see Figure 6.3a) and amplitude of maximum grip aperture was smaller (see Figure 6.3b) for the incongruent than for the congruent competition condition.

All in all these results suggest that the incongruent attitude of the actor model modified the kinematic pattern of the naïve participant. When in cooperation tasks the partner assumed a competitive attitude, the kinematic pattern of the naïve participant become more similar to a competitive than to a cooperative pattern (see Figure 6.4). The opposite pattern was found when the incongruent attitude assumed by the actor model was cooperative (see Figure 6.4). That is, when the incongruent attitude assumed by the actor model was cooperative (but the task was to compete), the kinematic pattern of the naïve subject became more similar to a cooperative than to a competitive pattern (see Figure 6.4).

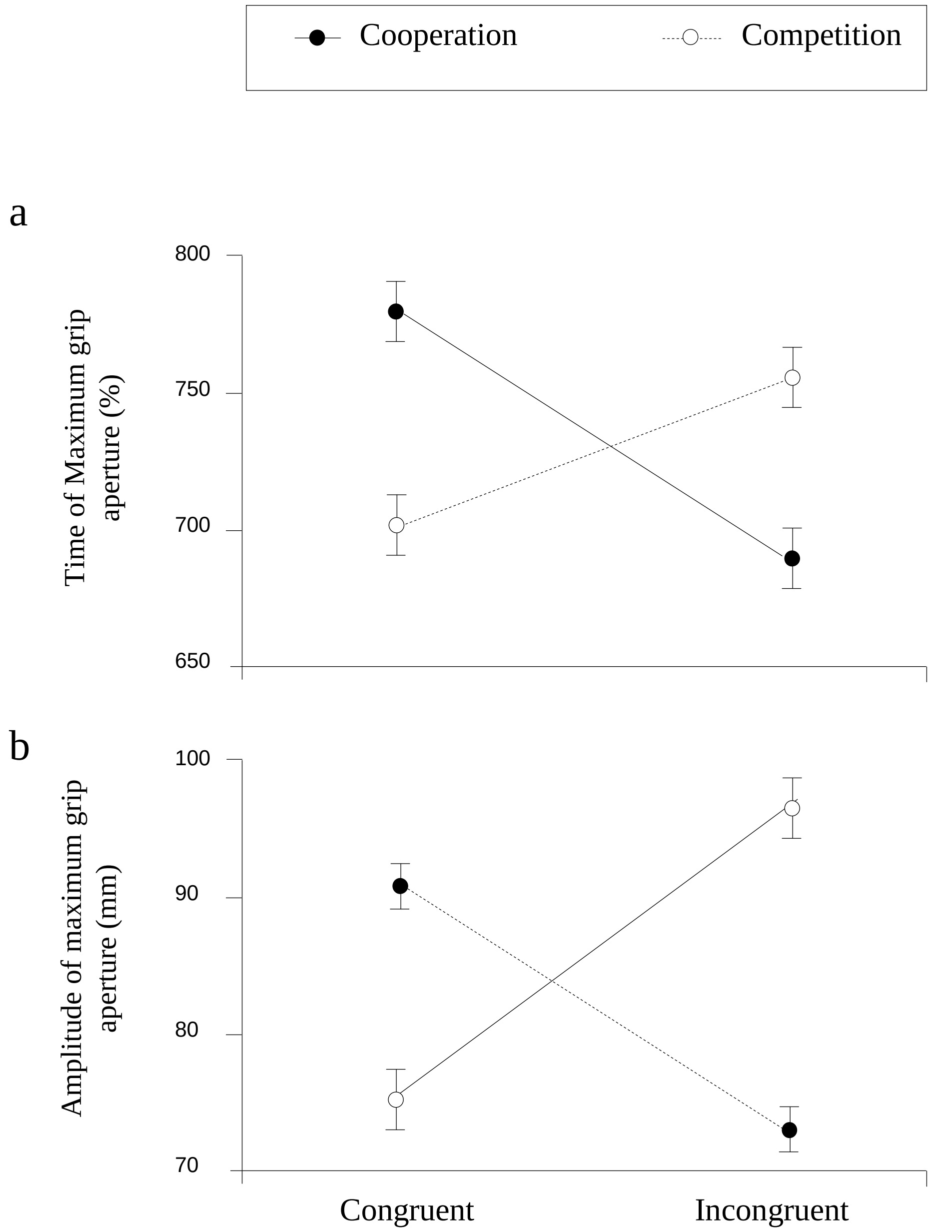
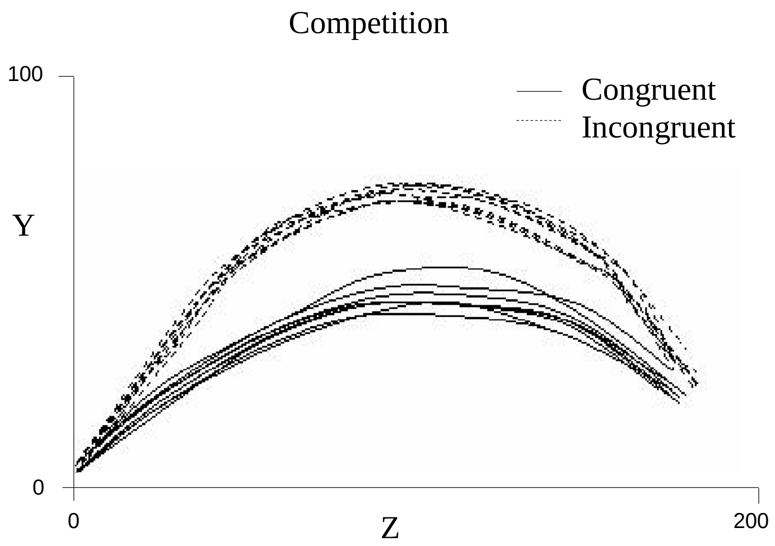


Figure 6.3 Graphical representation for the interaction type of task by type of trial for time of maximum grip aperture (Panel 'a') and amplitude of maximum grip aperture (Panel 'b').

a



b

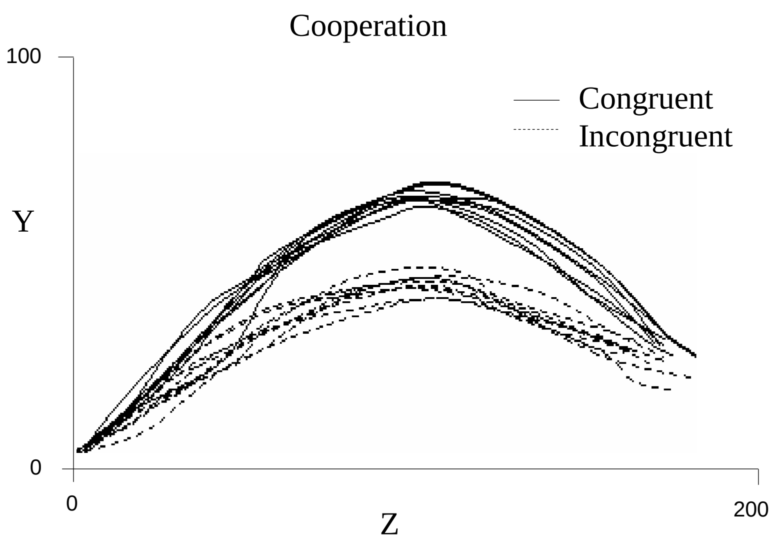


Figure 6.4 Illustrated are spatial path trajectories for all ten trials of a representative subject (L.M.) for both the congruent and incongruent competitive (a) and cooperative (b) tasks. Bars represent the standard error.

6.3.3 Correlation Analysis

As previously demonstrated (Georgiou et al., 2007), all the parameters considered for this analysis revealed significant correlations between the movement of the agents for the congruent cooperative condition and no correlation for the congruent competitive condition (see Appendix IV). Interestingly, except for a few cases, for the incongruent cooperative condition such correlations were lost, whereas for the incongruent competitive condition significant correlations were found for the measures of interest (see Appendix IV).

6.4 DISCUSSION

The main aim of the present study was to ascertain whether in a social context the kinematic parameters are influenced by the cooperative or competitive stance of the participants. To this end, we included an experimental manipulation intended to create a mismatch between task instructions and partner's attitude. In line with our predictions, the effects of such mismatch were evident on the kinematics of the naïve agent. In particular, cooperating with a partner displaying the intention to compete rendered the agent's action more competitive. The opposite effect emerged when competing with a partner displaying the intention to cooperate: the kinematic pattern of the agent became similar to a cooperative pattern. These results complement and extend previous findings concerning the sensitivity of kinematics to prior intentions (Georgiou et al., 2007). We demonstrated that the planning and execution of a goal directed action is modulated by the intention of the agent to act in a social context. The present findings further extend the notion of a social dimension for cooperative and competitive behaviours. Kinematics is sensitive to the social intention displayed by the partner and do not simply reflect the agent's intention. Paradoxically, both your intention and mine are reflected in the kinematics of my reach to grasp movement.

6.4.1 From Motor to Prior Intentions: the Influence of Others' Mental States on Kinematics

The idea that the mental states of another's person can affect the agent's action was already present in the literature under the concept of motor interference (Castiello, 2003). In a series of experiments, an actor reached and grasped for an object presented in isolation or flanked by a distractor. Subsequently, an observer was required to perform a similar action toward the target object, but always in the absence of the distractor. The kinematics of both the human actor and the observer were affected by the presence of the distractor. Unexpectedly, similar effects were found in the observer's kinematics during the trials in which the actor was seated in front of the observer but no action was demonstrated. These findings were interpreted as evidence that even in the absence of any overtly executed action other people's motor intention can influence the agent's kinematics. The present study identifies new conditions for understanding the link between kinematics and mental states. If kinematics were simply sensitive to the others' action and motor intention, a similar kinematical pattern should be observed in the reach to grasp phase, regardless whether the attitude of the partner was congruent or incongruent with the task instructions. The existence of a difference between congruent and incongruent trials strongly suggests that the sensitivity of kinematics may extend beyond the other's motor intentions. In other words, the kinematics of an agent's action is influenced by the partner's prior intention.

6.4.2 Incongruent Trials: Implications for the Explanation of the Kinematic Effects

A potential objection that could be made against this interpretation concerns the motor constraints imposed by the task. Could the differences in the kinematics of the agent simply reflect the motor constraints imposed by the task? Since cooperative and competitive actions may require different control strategies, it might well be that these strategies already emerged in the kinematics characterizing the reach-to-grasp phase (Georgiou et al., 2007). Whereas such explanation could account for the congruent conditions, an interpretation in terms of motor strategies does not hold for the incongruent conditions. This is because for the incongruent conditions the kinematics for the reach-to-grasp phase contrasted with the action subsequently performed by the agent during the interaction phase (i.e., cooperative or competitive). If kinematics simply reflected the adoption of a certain motor strategy, then no difference in kinematics should have been observed between reach-to-grasp movements preparing the same subsequent action.

The natural question concerns the mechanisms underlying the effect of the incongruent manipulation: what is it that causes the changes in the agent's kinematics on incongruent trials? What is the kinematics of the agent sensitive to?

Facial expression and body posture are important sources of information about conspecifics inner state (Allison, Puce, & McCarthy, 2000; Frith & Frith, 2006a). In the context of social interaction, they might allow an agent to anticipate what the partner is likely to do next, i.e. to infer her prior intention (Frith & Frith, 2006b). In this connection, a possible explanation of the incongruent manipulation effect reported here is that agents attributed to the partner an incongruent intention from the observation of these visual cues and this led to an automatic change in their kinematics. In this view, the changes in the kinematics of the agents would reflect the direct effect of the partner's attitude.

Another possible explanation is that the effect reflects a change in the actor's kinematics. For instance, during the incongruent cooperative conditions, the movement of the actor was already faster during the reach-to-grasp phase of the action. This decrease in the actor's movement duration could have plausibly influenced the participants' kinematics. The naive participant would simply mimic the movement of the actor. In this view, the reported effects might reflect a form of mimicry, i.e. the result of an automatic link between perceiving a behaviour and performing that behaviour (Chratrand & Bargh, 1999; Lakin & Chartrand, 2003)

To summarize, there are two possible non-mutually exclusive interpretations of the presented data, either an interpretation based on the actor's social attitude (facial expression and posture) which then influenced the participant's kinematics, or an interpretation based on a direct effect of the actor's kinematics on the participant's action. I will further address this issue in Chapter 7, Experiment IV.

6.4.3 Coordination Between Agents

A further issue to consider when interpreting these data is concerned with the action coordination between agents. We expected that disturbing the kinematics of the naïve agent would annul the correlations between key kinematic parameters for the incongruent cooperative task. Indeed, correlation analysis confirmed this prediction. Surprisingly, significant correlations in the movements performed by the two participants were chiefly observed for the incongruent competitive task. These findings may rule out the possibility that the incongruent manipulation produced a non-specific interference effect on the kinematics of the agent. In these circumstances no significant correlation should be observed for key kinematic parameters for the incongruent task.. The very fact that we found significant correlations for the incongruent competitive task, but not for the incongruent cooperative task proves that the effect of the incongruent manipulation was intention-specific. The incongruent manipulation did not simply interfere with the execution of the agents' actions, but had the potency to induce a reversal in their kinematical patterning. As a result, cooperation in the form of action coordination was attained without being represented or intended as such. Recently, Wilson and Knoblich (2005) proposed a possible mechanism by which action coordination in social contexts might be achieved. On the basis of the assumption that perceiving other people's behaviour activates imitative motor plans in the perceiver (Buccino, Binkofski, & Riggio, 2004; Grezes, Armony, Rowe, & Passingham, 2003; Rizzolatti & Craighero, 2004) they suggest that these motor plans are used simultaneously for predicting the future course of others' action and for planning an appropriate complementary action.

This account implies that a rapid integration of self- and other-produced actions in real time can be achieved. Therefore, given the 'simultaneous' nature of our tasks it is tempting to speculate that the incongruent manipulation effect observed in our study is achieved through a similar real-time integration mechanism.

These findings have important implications for the interpretation of the influence of the partner's attitude in the context of social interaction. First, they shows how the attitude of the partner can have the potency to destroy cooperation (on incongruent cooperation trials), but also the effect to establish a cooperation (on incongruent competitive trials). Second, they provide evidence of a social dimension of cooperative behaviour exceeding the economic dimension. To explain, cooperating with a competitive partner might be extremely unfavourable in terms of outcomes: a mere economic explanation may thus account for the effect of attitude of the partner on cooperative incongruent trials. An economic explanation does not hold, however, for incongruent competitive trials. Compete with a cooperative partner might be in fact even more favourable that compete with a competitive partner. The fact that the kinematic pattern of the agent becomes nevertheless cooperative suggests that at least in some circumstances the attitude of the partner may prevail on the outcome.

7. Modulation of the action control system by social intention[6]

Abstract

A universal feature of the motor system is the ability to react to sudden changes in the environment.

Four experiments investigated the influence of a sudden social request on the kinematics of a pre-planned action. In Experiment 1 participants were requested to grasp an object and then locate it within a container (unperturbed trials). On 20% of trials a human agent seated nearby the participant unexpectedly stretched out her arm and unfolded the hand as to ask for the object (perturbed trials). In the remaining three experiments similar procedures were adopted except that: (i) the human agent was replaced by a robotic agent, (ii) the gesture performed by the human agent did not imply a social request and (iii) the gaze of the human agent was not available. Only when the perturbation was characterized by a social request involving a human agent, there were kinematic changes to the action directed to the target.

[6] Sartori, L., Becchio, C., Bulgheroni, M., & Castiello U. (*in press*). Modulation of the action control system by social intention: unexpected social requests override pre-planned action. *Journal of Experimental Psychology: Human Perception and Performance.*

Conversely, no effects on kinematics were evident when the perturbation was caused by the robotic agent or by a human agent performing a non-social gesture. These findings are discussed in the light of current theories proposed to explain the effects of social context on the control of action.

7.1 INTRODUCTION

In everyday life we are often confronted with situations in which unexpected changes occurs while we are acting. Situation of this kind can be recreated in a laboratory setting in which an unexpected event, or perturbation, occurs during the performance of the task being studied (Haggard, 1994).

Perturbation experiments have been particularly influential in motor control research, in which they have been used to investigate how pre-planned actions are adjusted in response to sudden changes of object's intrinsic (e.g., size) and extrinsic (e.g., location) properties. For example, Paulignan, Mackenzie, Marteniuk, and Jeannerod (1991) studied the ability of the motor system to accommodate a change in object location that coincided with movement initiation. They placed three cylinders on a table in front of the participant. The usual target to reach and grasp was the central cylinder. By unexpectedly shifting illumination (20% of trials) from the central to one of the laterally placed cylinders at reaching movement onset, they were able to create the impression that in these trials the target had changed location. This apparent change in object location amounted to a perturbation of the prehensile movement. They found that participants took no more than 100 ms to initiate a corrective arm movement in response to the displacement of the target, with the earliest behavioural change manifesting in the parameter of arm acceleration.

A similar paradigm was used by Paulignan, Jeannerod, Mac Kenzie and Marteniuk (1991; see also Castiello, Bennett, & Stelmach, 1993) to study the corrective responses to a sudden visual change in object size, without alteration of object position. Participants were presented with two targets: a small-diameter cylinder, vertically inserted into the centre of a large-diameter cylinder. Perturbations could be achieved by interchanging illumination of the two, as for the perturbation of object location. Changes were evident in the timing and amplitude of maximum hand aperture, as well as in the reaching component of the movement.

Subsequent studies demonstrated rapid on-line adjustments for reactions to sudden changes in the orientation (Desmurget & Prablanc, 1997; Desmurget, Prablanc, Arzi, Rossetti, Paulignan & Urquizar, 1996; Desmurget, Prablanc, Rossetti, Arzi, Paulignan, Urquizar & Mignot, 1995), the speed (Brenner, Smeets, & de Lussanet, 1998), and the weight (Brouwer, Georgiou, Glover, & Castiello, 2006) of target objects. The logic of the experiment was the same in each case. A perceptual change in the environment of the movement was unexpectedly produced at the time the hand started to move. Typically, the response to the perturbation occurred within a 100-300 ms time window after the change depending on the perturbed object feature.

An approach common to all these studies is that of restricting the perturbation to changes in the physical environment within which the movement occurred. A challenging, unexplored question is whether such rapid on-line adjustments can also be noticed when sudden changes are applied to the social environment in which the action takes place.

Previous studies on the possible influence of the social context on motor processes have largely focused on the planning phase. That is, the phase operating prior movement execution. As demonstrated in our previous study, evidence that planning an action is influenced not solely by the physical but the social environment has been provided recording kinematics of actions directed towards conspecifics (see Chapter 1). In that case results revealed specific patterns of spatial trajectories for single intended actions and social intended actions. Planning incorporates overarching social goals into the action plan. For instance, the length of wrist trajectory was longer and the amplitude of wrist trajectory height was higher for the 'social' than for the 'single-agent' condition.

Along these lines, Meulenbroek and colleagues (2007) demonstrated that in a sequential motor task a transfer of performance parameters takes place between co-actors involved in transferring objects. First, one of the two actors was asked to pick up a cylinder from a nearby location on the table and put it in the middle of the table. Subsequently, the other actor was asked to fetch the cylinder and to reposition it in a nearby target area. Variations in task constraints concerned both the size and the weight of the transferred cylinder. Time series analysis of the lifting heights indicated that the actor who fetched the cylinder as second benefited from movement observation. Specifically, the actor who fetched the object first showed systematically larger surprise-effect than the actor who was asked to transport the object after the first actor had done so. Surprisingly, the influence of other's action is also evident even when ignoring these actions would be more effective for task performance. For instance, Kilner and colleagues (Kilner, Paulignan, & Blakemore, 2003) found that observing continuous human arm movements significantly interferes with ongoing executed movements if the observed movements are qualitatively different from the movements being made. Sebanz and colleagues (Sebanz, Knoblich & Prinz, 2003; Sebanz, Knoblich, Prinz, 2005) demonstrated that for an interference effect to take place it is not even necessary that the action of another person is observed. Simply knowing that another person is performing a similar task may be sufficient to produce an action selection conflict.

Altogether, these studies suggest that planning integrates information about the social environment. The question addressed by the present study is whether information about the social environment also impacts on the on-line control phase, i.e. during the execution of the movement. It has been proposed that planning and on-line control of action each serves a specialized purpose different from the other and utilizes distinct visual representations (Glover, 2004). On-line control can assume two different forms. A usual 'feedback control' form takes place when a target object is shifted position slightly during movement execution. Alternatively, if some stimulus event signalled that the person should change the target of the action from one object to another, then it is likely that an on-line reprogramming of the movement would be required. Here, we investigated whether on-line control of the latter type is influenced by the social dimension of the observed change. As expected, we demonstrated that exposure to an unexpected social interactive gesture by another agent affects the participants' kinematics.

7.2 Experiment I – Unexpected social requests

In this study we investigated the influence of a sudden and unexpected social request on the kinematics of a pre-planned action. Participants were requested to grasp an object and then locate it within a container (unperturbed trials). In 20% of trials a human agent seated nearby the participant unexpectedly stretched out her arm and unfolded the hand as to ask for the object (perturbed trials). We reasoned that if the on-line control system is sensitive to sudden 'social' changes within the environment, then exposure to an unexpected social request should perturb the execution of the pre-planned action. Kinematics changes on participants' action directed to the target were noticed.

7.2.1 Method

7.2.1.1 Participants

Fifteen students (10 women and 5 men, ages 20 – 31 years) took part in the experiment.

7.2.1.2 Stimulus

The stimulus was an egg shaped object (long axis = 5.7 cm; weight ~ 50 g) positioned on the target pad (see Chapter 2) at a distance of 25 cm from the hand starting position along the midsagittal plane (see Figure 7.1a).

7.2.1.3 Procedures

Participants were requested to start the action after a tone (880 Hz/200 ms) was presented, and then reach for, grasp, lift the target object and transport it to a new location in which a round container (12 cm diameter) was placed. The container was located on the end pad to the right of the target at a distance of 28 cm (see Figure 7.1a). Participants received written instructions and were explicitly told to complete this basic task irrespective of whatever event took place in the near environment. During these trials a co-experimenter was seated on the left side of the working surface (see Figure 7.1b). Within a block of trials (N = 50) two types of trials were intermingled: (i) unperturbed trials (80% of the total number of trials) in which the task described above was completed and the co-experimenter seated on the left side of the working surface simply observed the scene; (ii) perturbed trials (20% of the total number of trials) in which at the time the starting tone was presented and the participant started the action, the co-experimenter seated on her left stretched out her right arm and unfolded the hand in a 'give-me-the-object' posture (see Figure 7.1c). The co-experimenter was signalled in which trials she should stretch out her arm by means of an infrared light pointed at her feet, below the table surface. The signalling occurred before the starting tone was presented and was not visible by the naïve participant. The co-experimenter was introduced as another participant (confederate). To reduce expectancy and rhythmical effects, the duration between the end of the trial and the presentation of the tone for the new trial was varied.

7.2.1.4 Data Analysis

For each dependent variable, the means for each participant were entered into a within-subjects analysis of variance (ANOVA). The within subjects factor was experimental condition (unperturbed, perturbed). We further explored differential trajectory patterns by means of a break detection algorithm (Castiello et al., 1993; see Appendix I).

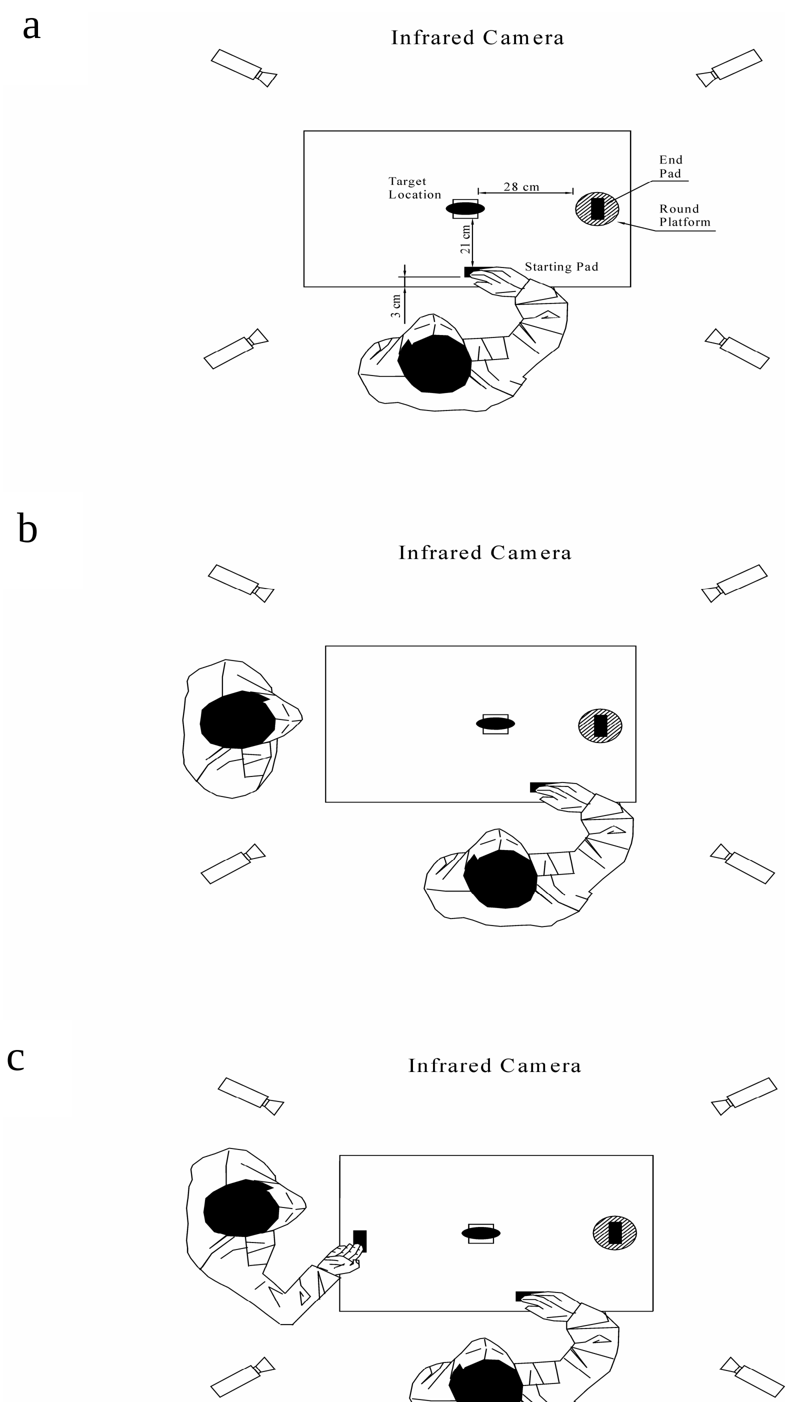


Figure 7.1 Experimental set-up (panel ‘a’). Graphical representation of an ‘unperturbed’ trial. The participant’s task is to reach towards, grasp the object and locate it within a container in the presence of a ‘passive’ co-experimenter (panel ‘b’). Graphical representation of a ‘perturbed’ trial. In these trials (20%) the participant’s task is the same as for ‘unperturbed’ trials, but the co-experimenter stretches out her right arm and unfolds the hand in a ‘give-me-the-object’ posture (panel ‘c’).

7.2.1.5 Results

7.2.1.5.1 Reach-To-Grasp Phase

For this phase analysis of spatial trajectories revealed that the maximum curvature of the arm trajectory path was reached earlier for perturbed than for unperturbed trials [$F_{(1,14)} = 5.3$, $p < .05$; see Figure 7.2 – black arrows and Appendix V]. A further inspection of Figure 7.2 indicates that the maximum deviation for unperturbed trials was to the right, whereas for perturbed trials it was to the left of the ideal line linking the starting position with the target object (see Appendix V). In addition, for perturbed trials the arm trajectory path started to veer significantly towards the co-experimenter (left deviation) during the initial phase of the movement (please refer to the white arrow in Figure 7.2). At the same time the arm trajectory path for unperturbed trials maintained an almost straight path with slight deviations to the right.

The break detection algorithm allowed determining at which point in time trajectories for perturbed trials started to significantly divert from those related to unperturbed trials. The results indicated that the first significant change was evident on average after 165 ms after the co-experimenter started her movement [$t(45) = 22.4$, $p < .001$].

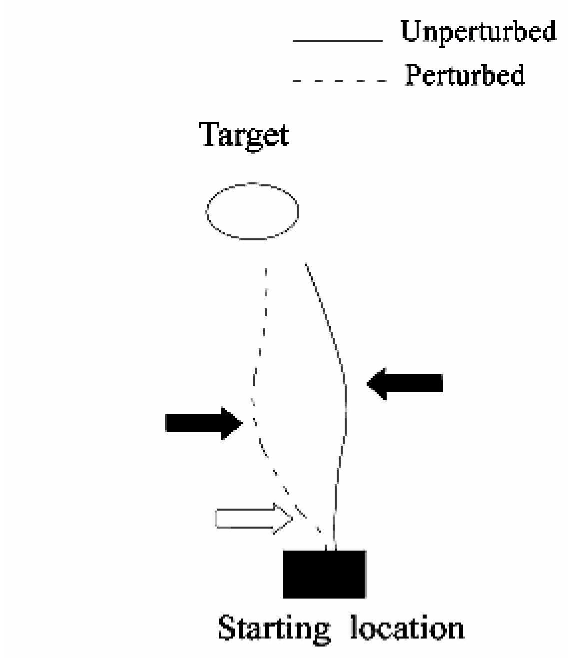


Figure 7.2 Wrist average spatial paths in the plane of the table for unperturbed (solid line) and perturbed (dashed line) trials. Black arrows indicate the point at which trajectories reached the maximum deviation. The white arrow indicates when trajectories for unperturbed and perturbed trials start to significantly diverge.

7.2.1.5.2 Place Phase

Strikingly, during this phase, even though the participants were instructed to place the target on their right side upon the platform, in some trials they totally ignored the instruction and deviated the arm trajectory path towards the human co-experimenter, placing the object in the co-experimenter's hand (see Figure 7.3). Some others started the action maintaining the arm trajectory path along the midline then they stopped the action, performed a slight movement towards the platform, but inevitably, they went for the co-experimenter's hand, suggesting that the social request had the potency to override the initial movement program. The analysis for the trials in which the task was correctly completed, therefore excluding from the analysis trials in which the participant handed the object to the co-experimenter (20% of the total number of perturbed trials, i.e., 150), also revealed effects of the perturbation. The maximum height of the wrist trajectory from the working surface was higher [$F_{(1,14)}$= 10.4, $p < .001$; see Figure 7.4 and Appendix V] and it was reached later in time [$F_{(1,14)}$ = 7.8, $p < .01$; see Figure 7.4 and Appendix V] for perturbed than for unperturbed trials.

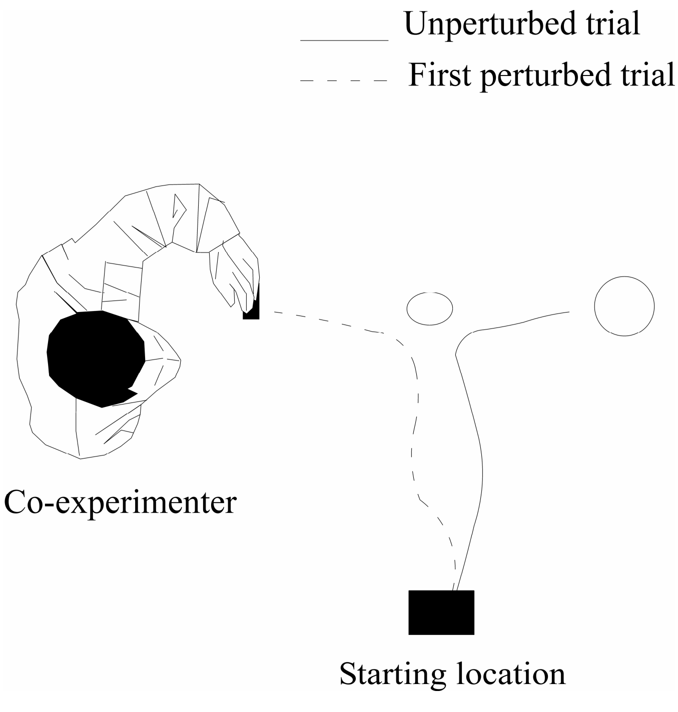


Figure 7.3 Example of trajectories of a representative participant during both the 'reach-to-grasp' and the 'place' phase for an unperturbed (solid line) and the first perturbed (dashed line) trial. Note that this figure refers to one of the participants who during the first perturbed trial neglected the task instructions and handed the object to the co-experimenter.

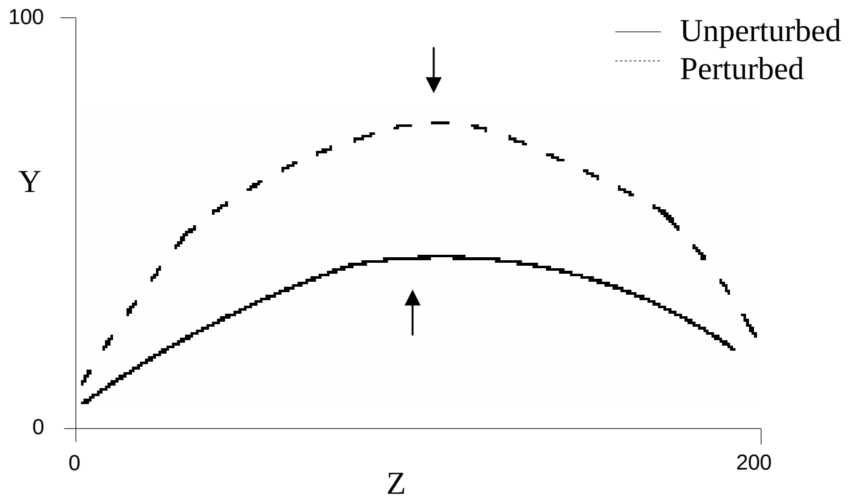


Figure 7.4 Average amplitude of maximum wrist height for unperturbed (solid line) and perturbed (dashed line) trials in Experiment 1. Mean trajectories for the 'place' phase are reported. Values on the axis are in millimetres (mm). Arrows indicate the peak of trajectory height. Axis *z* = sagittal axis; axis *y* = vertical axis.

7.3 Experiment II – A robotic agent

As previously demonstrated, exposure to a social request is critical for the perturbation effect to occur. However, one might wonder whether the use of a robotic-arm may exert a similar effect. To test this possibility in the present experiment we replaced the human arm with a robotic arm model, which was programmed as to execute a movement similar to the human agent.

This study was specifically designed to disentangle the contribution of social factors from the contribution of biological factors in determining the perturbation effect. We reasoned that if the perturbation effect is due to the biological nature of the event, then no differences in performance should be revealed when comparing unperturbed and perturbed trials in a human-robot interaction.

7.3.1 Method

7.3.1.1 Participants

Fifteen students (8 women and 7 men, ages 20 – 25 years) volunteered to participate.

7.3.1.2 Robot

The robotic arm was custom-designed and looked like an average human forearm, it was mounted on a metal frame, and moved from a vertical to a horizontal position. It was placed on the left side of the working surface and all the fingers and the thumb had a common movement, so as to mimic the opening of a human hand. The construction was electromechanical and controlled by an 87C751 micro controller. The hand was constructed of nylon cords for the tendons, silicon rubber for the joints, and wooden dowels for the bones (see Figure 7.5). Movement was provided by a DC electric motor that tensed the tendons to open the hand. Springs were used to store energy and thus reduce the required power and size of the motor. The arm length was approximately 0.5 m.

7.3.1.3 Stimulus

The stimulus was the same as for Experiment 1 (see Chapter 7.2, Figure 7.1a).

7.3.1.4 Procedure

The robot was programmed to start moving when the starting tone was presented. Movement duration and the occurrence of kinematic landmarks (i.e., time to peak velocity) were comparable to those of the co-experimenter in the previous experiment. The movement of the robot was quite smooth, and the action of stretching out the arm and unfolding the hand in a 'give-me-the-object' posture was analogous to that of the human co-experimenter.

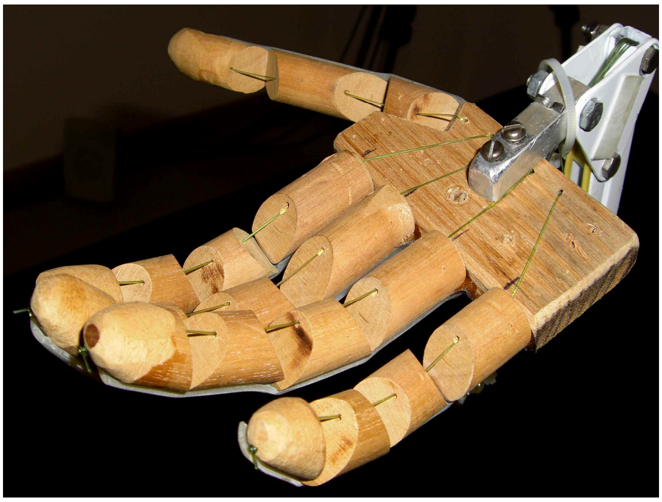


Figure 7.5 In this picture is shown the robotic arm constructed of nylon cords for the tendons, silicon rubber for the joints, and wooden dowels for the bones.

7.3.1.5 Data Analysis

This was the same as for Experiment 1 (see the 'Data analysis' section in Chapter 7.2).

7.3.1.6 Results

An important aspect of the results is that all the participants ignored the robotic arm and fulfilled their task with no hesitations. Therefore, no differences whatsoever were found when comparing unperturbed and robotic perturbed trials in neither the 'reach-to-grasp' nor the 'place' phases. Specifically, for the 'reach-to-grasp phase' the maximum curvature of the arm trajectory path was reached at a similar time for both perturbed and unperturbed trials [$F_{(1,14)} = 0.5$, $p > .05$; see Appendix V]. The maximum deviation of the trajectory was similar for both perturbed and unperturbed trials and no evidence of left deviations for perturbed trials was detected (see Appendix V). That is, for both perturbed and unperturbed trials the trajectory path was slightly curved to the right. Application of the break detection algorithm revealed that at no points in time trajectories for perturbed trials started to significantly divert from those related to unperturbed trials. For the 'place' phase there were no cases in which the participants ignored the instruction and veered the arm trajectory path towards the co-experimenter. Finally, the maximum height of the wrist trajectory from the working surface was similar for both perturbed and unperturbed trials in terms of amplitude [$F_{(1,14)} = 1.2$, $p > .05$; see Appendix V] and time [$F_{(1,14)} = 4.5$, $p > .05$; see Appendix V]. Altogether these results suggest that the lack of perturbation effect was due to the exposure to a non-biological movement. In order to corroborate this conclusion we compared the results obtained for Experiment 2 with those obtained for Experiment 1. An ANOVA with Experiment (1, 2) as a between-subjects factor and experimental condition (perturbed, unperturbed) as a within-subjects factor was carried out for each of the dependent measures of interest. The interaction between experiment and experimental condition was not significant for the maximum curvature of the arm trajectory path [$F_{(1,28)} = 0.9$, $p > .05$] the time and amplitude of the maximum height of the wrist trajectory [$F_{(1,28)}=0.1$, $p>.05$; $F_{(1,28)}= 0.04$, $p > .05$, respectively].

7.4 EXPERIMENT III – A NON-COMMUNICATIVE GESTURE

This experiment was complementary to the previous one. In demonstrating no perturbation effect during robotic arm movement, we revealed that the effect is related to biological movement.

Here we sought to further refine the nature of the perturbed trials effect asking whether a human arm movement conveying no-social intention would exert a similar effect. In this study we aimed at clarifying the role played by intention in the perturbation effect. We asked the human agent to perform a sudden movement as to recreate almost the same trajectory pattern performed in the original experiment (see Experiment I). The relevant difference was in the type of hand movement: whereas in the previous one, the experimenter's hand movement clearly conveyed a social request ("Give me the object"), here the human agent laid the hand on the table, displaying neither the intention to communicate nor to socially interact with the participant.

If the perturbation effect depends on the observation of a biological human movement, perturbation effect should be the same irrespective of whether one observes a sudden social gesture by a human agent (see Experiment I) or a human movement conveying no social intentionality (present experiment).

In contrast, if the perturbation effect relates to the social nature of the observed gesture, then no similar perturbation effect should be revealed when comparing unperturbed trials and human-non social perturbed trials.

7.4.1 Method

7.4.1.1 Participants

Fifteen students (8 women and 7 men, ages 20 – 25 years) volunteered to participate.

7.4.1.2 Stimulus

The stimulus was the same as for Experiment 1 (see Chapter 7.2, Figure 7.1a).

7.4.1.3 Procedure

The co-experimenter performed an action which did not display the intention of either to communicate or socially interact with the participant (see Figure 7.6). The gesture performed by the co-experimenter was to run her fingers through her hair using the right hand (see Figure 7.6a) and then lower the hand on the working surface in a posture similar to the 'requesting' posture adopted for the perturbed trials in the original experiment (see chapter 5), but without the intention to convey any social request (see Figure 7.6b).

7.4.1.4 Data Analysis

This was the same as for Experiment 1 (see the 'Data analysis' section in Chapter 7.2).

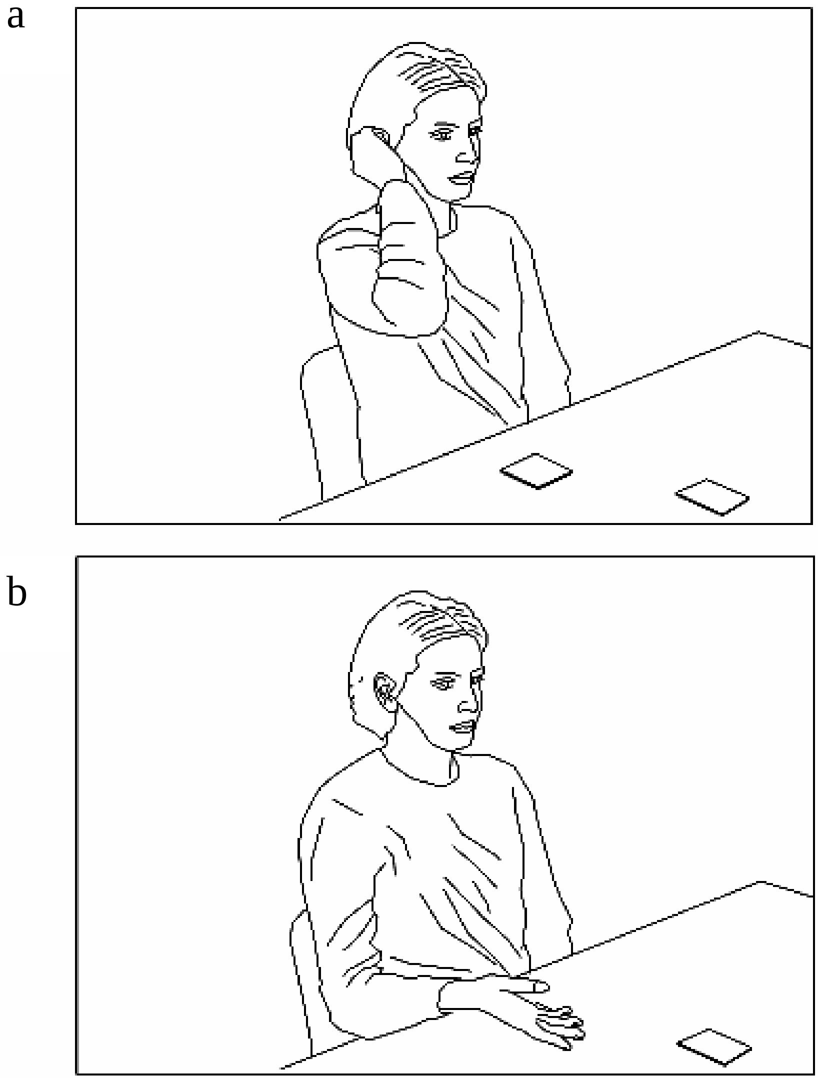


Figure 7.6 Schematic representation of the movement performed by the co-experimenter. Panel 'a' represents the co-experimenter running her fingers through the hair. Panel 'b' represents the final posture and position reached by the hand.

7.4.1.5 Results

No significant differences for the considered dependent measures were found when comparing unperturbed and human non-social perturbed trials in neither the 'reach-to-grasp' nor the 'place' phases. As found in the previous experiment (see Experiment II) the maximum curvature of the arm trajectory path during the 'reach-to-grasp' phase was reached at a similar time for both perturbed and unperturbed trials [$F_{(1,14)} = 0.0$, $p > .05$; see Appendix V]. Similarly, no differences between perturbed and unperturbed trials were found for the maximum deviation of the trajectory path and no evidence of left deviations for perturbed trials were detected (see Appendix V). Application of the break detection algorithm did not reveal points in time at which trajectories for perturbed trials started to significantly divert from those related to unperturbed trials. The lack of significant results also extended to the 'place' phase. In no cases the participants veered the arm trajectory path towards the human co-experimenter as to place the object in the co-experimenter's hand. With respect to the height of the wrist trajectory from the working surface no significant differences were found for perturbed and unperturbed trials in terms of both amplitude [$F_{(1,14)} = 1.1$, $p > .05$; see Appendix V] and time [$F_{(1,14)} = 0.2$, $p > .05$; see Appendix V]. In order to further explore such results we run comparison analyses with Experiment (I, III) as a between-subjects factor and experimental condition (perturbed, unperturbed) as a within-subjects factor for each of the dependent measures of interest. The results for these comparison analyses indicate that the interaction experiment by experimental condition was significant for the maximum curvature of the arm trajectory path [$F_{(1,28)} = 5.2$, $p < .05$], and the time and amplitude of the maximum height of the wrist trajectory [$F_{(1,28)} = 8.1$, $p < .05$; $F_{(1,28)} = 7.2$, $p < .05$, respectively].

7.5 EXPERIMENT IV – EFFECTS OF GAZE

Results from the previous experiment (see Experiment III) suggest that it is the intentional component embedded within the perturbation, which is critical for the revelation of the perturbation effect reported in Experiment I. In this experiment gaze manipulation was chosen because, as previously demonstrated, gaze is one of the most important cues for the attribution of intentionality (Allison et al., 2001; Castiello, 2003; Pelphrey & Morris, 2006). From the gaze of another person, we can infer what another person might be interested in or what she might desire and, consequently, what she might want to do next (Frischen, Bayliss, & Tipper, 2007). When gaze is occluded, processing her intention might become a less automatic process (Pierno, Becchio, Turella, Tubaldi & Castiello, 2007). This experiment was designed to manipulate the co-experimenter's intentionality by allowing or preventing the processing of her gaze. If gaze processing is fundamental for the determination of the reported effect, then preventing access to gaze cues should diminish the potency of the co-experimenter's gesture. In contrast, if the intentionality of the gesture is chiefly conveyed by the "Give me the object" hand posture, then, independently from gaze, a perturbation effect should be evident.

7.5.1 Method

7.5.1.1 Participants

Fifteen students (11 women and 4 men, ages 19 – 25 years) volunteered to participate.

7.5.1.1 Stimulus

The stimulus was the same as for Experiment 1 (see Chapter 7.2, Figure 7.1a).

7.5.1.2 Procedure

Participants performed two blocks of 60 trials in a counterbalanced order. In one block the gaze of the human co-experimenter was available to participants as in the original experiment (see Chapter 7.2). In the other block the gaze of the human co-experimenter was covered by a mask.

The percentage of perturbed and unperturbed trials within each block remained the same as for the previous experiments (i.e., 80-20%). For each dependent measure of interest an ANOVA with gaze (present, absent) and experimental condition (unperturbed, perturbed) as within-subjects factors was carried out.

7.5.1.3 Data Analysis

This was the same as for Experiment 1 (see the 'Data analysis' section in Chapter 7.2).

7.5.1.4 Results

Erroneous trials in which the participants handed the object to the co-experimenter were 38 (17% of the total number of trials) for the 'gaze' condition and 25 (11%) for the no-gaze condition. As for the original experiment (see Chapter 7.2), these trials were not included within the analyses whose results are described below.

7.5.1.4.1 Reach-To-Grasp Phase

Concerning this phase, the interaction between gaze and experimental condition was significant for the time at which the maximum trajectory deviation occurred [$F_{(1,28)} = 4.6$, $p < .05$]. Post-hoc contrasts revealed that when gaze was available the maximum trajectory deviation occurred later for perturbed than for unperturbed trials [$p_s < .05$; see Appendix V]. When the co-experimenter gaze was unavailable, the time at which the maximum trajectory deviation was reached was similar for both perturbed and unperturbed trials (see Appendix V). Importantly, early left deviations as previously found (see Chapter 7.2) were found only for the gaze available condition (see Appendix V). When the gaze was not available, the arm trajectory path showed right deviations as found in Experiments II and III. Application of the break detection algorithm indicated that only for the gaze available condition spatial trajectories for perturbed and unperturbed trials started to significantly diverge during the reach-to-grasp phase. Specifically, this occurred 171 ms after the co-experimenter started her movement [$t = 31.42$, $p < .001$].

7.5.1.4.2 Placing Phase

For the ‘place’ phase, the main factor experimental condition was significant for the time and the amplitude of maximum height of the wrist trajectory [$F_{(1,1)} = 14.34$, $p < .001$; $F_{(1,1)} = 10.5$, $p < .01$, respectively]. Specifically, the time and amplitude of the maximum height from the working surface reached by participants was earlier (369 vs. 385 ms) and lower (131 vs. 134 mm) for unperturbed than for perturbed trials.

7.6 GENERAL OVERVIEW ON EXPERIMENTS 1-4

Acting together with others is a fundamental human ability. This raises the possibility that we take others' actions into account whenever somebody acts around us. The present results, in particular, extend our knowledge about the influence of social context on action on-line control, suggesting that a motor response to a sudden change varies depending on the social salience of the observed change. Exposure to an unexpected movement conveying a social request exerted an effect of perturbation on pre-planned actions: by infringing instructions, participants tended to comply with the request (Experiment I). This suggests that the initial motor program to transport the object into the container was modified on the basis of the social request. Critically, no-perturbation effect was revealed for non-biological stimuli (Experiment II) and when the perturbation consisted in a human arm movement conveying no social or communicative intention (Experiment III). A pattern of results which was further confirmed in a series of analyses comparing the results of Experiment I with those obtained for Experiments II and III. These results suggest that the lack of perturbation effect was due to the fact that the gesture performed by the human co-experimenter did not carry any 'social' meaning. To sum up this pattern of results indicates that the exposure to an unexpected non-communicative human gesture is not enough to obtain a perturbation of the action kinematics as found in the original experiment (see Experiment I) in which the gesture was communicative in nature.

Finally, the manipulation of gaze cues affected the ‘reach-to-grasp’, but not the ‘place’ phase (Experiment IV). This result suggests that during the first reach-to-grasp phase having access to the gaze of the co-experimenter influenced the spatial trajectories. This may indicate that gaze is the first cue from which participants infer social intentions. However, during the ‘place’ phase the presence or absence of gaze seems to play no role (lack of the interaction between gaze and experimental condition). This may signify that during this phase the co-experimenter’ hand becomes a predominant cue which overrides the ‘gaze’ cue and therefore guides the participants’ response. This finding confirms the crucial role played by gaze in reading other persons’ intentions (Allison et al., 2000).

8. FINAL CONSIDERATIONS

The ability to act jointly with other people is an important feature of our species. But how this is achieved and to which extent social intentions are able to modulate motor control is still debated.

The experimental work included in the present thesis aimed at investigating this issue by asking participants to act under different 'social' circumstances. The implications of this experimentation for our understanding of the mechanisms underlying social motor control and some final considerations are outlined in the following sections.

8.1 IMPLICATIONS FOR A MOTOR THEORY OF SOCIAL COGNITION

Does the motor system play any role in understanding social intentions? Recent advances in the cognitive neuroscience of action have considerably enlarged our understanding of human motor cognition. In particular, the activity of the mirror system (Gallese, Fadiga, Fogassi & Rizzolatti, 1996) first discovered in the brain of nonhuman primates, provides an observer with the understanding of a perceived action by means of the motor simulation of the agent's observed movements.

This discovery has raised the prospects of a motor theory of social cognition. Human social cognition encompasses all cognitive processes relevant to the perception and understanding of conspecifics. So it includes the cognitive processes involved in the understanding of perceived actions performed by conspecifics. Thanks to their mind reading ability, human adults readily explain and predict human actions by representing and attributing to human agents a whole battery of internal unobservable mental states such as goals, intentions, emotions, perceptions, desires, and beliefs. In this respect, however, Jacob and Jannerod (2005) argue that there is a gap between mind reading and the psychological understanding of perceived actions. The authors disapprove the strategy to recur to the concept of motor simulation. The question is: could an observer represent an agent's social intention by simply simulating the agent's observed movements? According to their point of view, simulating an agent's movements might be sufficient for understanding his motor intention, but it is not sufficient for understanding the agent's prior intentions. In their famous thought-experiment they considered Dr Jekyll and Mr Hyde characters. Suppose that Dr Watson witnesses both Dr Jekyll's and Mr Hyde's actions. Presumably the very same mirror neurons produce the same discharge in Dr Watson's brain. Dr Jekyll's motor intention is the same as Mr Hyde's. However, Dr Jekyll's social intention clearly differs from Mr Hyde's. Simulating the agent's movements might allow an observer to represent the agent's motor intention, but it would not allow him to represent the agent's social intention. This is true if we presume that motor intentions translate in the very same kinematic pattern, regardless of social intentions. But this is not the case, as we have outlined in various experiments (see Chapters 3, 4, 5 and 6). We can therefore conclude that a motor theory of social cognition is, in fact, possible and kinematic analysis has proved to be a precise tool for studying such processes.

8.2 A TWO-WAY MOTOR CONTROL SYSTEM

In literature there is evidence for a dichotomy between the visual representations in the *planning* and in the *on-line* control of an action in humans, the so called 'Two-Way Motor Control System' (Glover, 2004). This evidence suggests that planning and control each serve a specialized purpose utilizing distinct visual representations. Evidence from behavioural studies have suggested that planning is influenced by a large array of visual and cognitive information, whereas on-line control is influenced solely by the spatial characteristics of the target, including such things as its size, shape, orientation, and so forth. However, so far, no extent has been made to ascertain the influence that *social* intentions exert on both planning and on-line control of action. This has been one of the aims characterizing my thesis.

8.2.1 Prior Social Intentions and the *Planning* Control System

Our findings suggest that prior social intentions translate into specific motor pattern and provide evidence for the existence of differences in motor patterning depending on social context and intention. Specific kinematic patterns distinguish and connote individually intended actions and actions motivated by social intentions (see Chapter 3). These differences, we surmise, may be used by the observer's motor system to discriminate between actions serving different intentions. If the very same action can serve different intentions (many-one assumption), then no information may be derived from actions in order to understand intentions. On the contrary, if intentions shape kinematics – as the present results show – mirroring an action may enable the observer to represent the agent's social intentions. The above considerations are in line with the proposal that we directly perceive intentions in the actions of others (Gallese, 2006). In most of our every day interactions, we have a direct, immediate understanding of other persons' intentions because their intentions are explicitly expressed in their embodied actions. As a consequence, when observing another person's action, we do not only see a physical movement, but we "see" an intentional action. What the present results add to these notions is the specific role played by kinematics in translating social intentions into specific motor patterns. Kinematics reflects differences in intentions, so that the same motor sequence assumes different features depending on the intention (social vs. individual, communicative vs. non communicative, cooperative vs. competitive. See Chapters 3, 4, and 5, respectively) motivating its execution. In particular, our data revealed that the imposition of a communicative intent is not neutral with respect to action kinematics: also the intention to communicate alters the parameters of the movement. Prejudice biases as well have proved to influence the planning control system (see Chapter 5). As we demonstrated, 'gender-driven' prior intentions are reflected in the kinematics, which is sensitive also to the cooperative or competitive attitude unexpectedly shown by the partner (see Chapter 6). This last study specifically outlined how both the agent's and the partner's intentions are reflected in the agent's kinematics through a real-time integration mechanism. Recently, Wilson and Knoblich (2005) suggested that imitative motor plans in the perceiver are used simultaneously for predicting others' action and for planning an appropriate complementary action. This account implies that a rapid integration of self- and other-produced actions in real time can be achieved. Therefore, the last experiment represents the ideal link connecting the study of how prior intentions are coded in motor plans and the research about how intentions in action influence the on-line control system).

8.2.2 Intentions in Action and the *On-Line* Control System

Results shown in Chapter 7 suggest for the first time that the exposure to a sudden *social* request produces reliable changes on the action *on-line* control system. Importantly, the present findings might provide some information regarding the timing of such mechanism. The very fact that we found a response to the socially relevant stimulus after 165 ms indicates that socially relevant stimuli are acknowledged by the motor system very early. This unveils how fast is the processing of the *social* meaning carried by sudden environmental changes. Moreover, only when the perturbation was characterized by a social request involving a human agent, there were kinematic changes to the action directed to the target. This result illustrates the influence of social context on the action on-line control system, suggesting that a motor response to a sudden change varies depending on the social salience of the observed change.

8.2.3 Modulation by Intentional Relevance

The lack of perturbation effect during human arm movements conveying no social intention is intriguing as it places new constraints on models put forward to explain how the brain represents movements. Our last study (see Chapter 7) suggests that movements may exert different effects on the observer's motor system depending on the perceived intentionality of the agent's gesture. Using a motor interference paradigm, Stanley, Gowen and Miall (2007) demonstrated that interference effects were present for both biological and non-biological movement when participants believed that they were observing a human movement. This suggests that the *intentional* stance of the participant, i.e. the fact that the participant views an entity as possessing intentions, might be a more important determinant than the biological origin of movement per se. Crucially, we did not observe the classic perturbation effect during no-gaze trials. If intentionality modulates the way biological motion is processed, then the absence of gaze cues might well explain why the perturbation effect was delayed in no-gaze trials.

8.3 BEYOND RE-ENACTMENT: EVIDENCE IN FAVOUR OF A COMPLEMENTARY MECHANISM

Raising an empty hand towards another person represents a specific request, equivalent, under many aspects, to a verbal utterance: "Give me the object". A possible explanation of the perturbation effect is that socially-motivated actions (like the request-gesture) act as an *affordance*[7] that activates an appropriate motor response. Once this request has been processed, the activation of the appropriate response is almost automatic: ignoring the instruction to put the object in a container, participants veered the trajectory path towards the human agent.

One interesting aspect of this behaviour is that it represents a *complementary* response to the human agent gesture. Knowing what the other is attending to in a particular action context provides important cues about the other's action goals and can elicit complementary actions in the observer.

[7] An affordance is a quality of an object, or an environment, that allows an individual to perform an action. Psychologist James J. Gibson originally introduced the term in his 1977 article *The Theory of Affordances* and explored it more fully in his book *The Ecological Approach to Visual Perception* in 1979. He defined affordances as all "action possibilities" latent in the environment, objectively measurable and independent of the individual's ability to recognize them, but always in relation to the actor and therefore dependent on their capabilities.

This behaviour is suggestive of a more complex mechanism than the simple re-enactment of perceived actions postulated by ideomotor theories. According to these theories (Greenwald, 1970; James, 1890; Jeannerod, 1999; Prinz, 1997), when an observer perceives somebody else performing a body gesture, the perception of that gesture will tend to activate its execution by the observer. As a result, the observer will tend to re-enact the observed action.

In the present study, the human agent stretched her hand towards right: if participants simply re-enacted the human agent's action, a deviation should be observed towards right. The fact that we observed a deviation towards left, i.e. towards the human agent, suggests that participants did not simply activated the representation of the gesture made by the human agent, but the representation of the complementary action. In other words, they responded to the perturbation programming an appropriate complementary action. As noted by Sebanz, Bekkering & Knoblich (2006), although social interaction sometimes may require imitative kinds of movements, in many situations imitating the actions of others would be dysfunctional. Successful interaction requires instead that the complementary movement is selected. This can only be achieved if activation of motor representations following observation is suppressed by a joint goal representation, so that one can perform actions dissimilar from those observed. It is likely that similar neurocognitive mechanisms govern goal-directed imitation and the selection of appropriate actions to achieve joint goals.

Perhaps the most important feature of joint action yet to be understood is how individuals adjust their actions to those of another person in time and space. Clearly, this cannot be explained just by the assumption that representations are shared. Although motor resonance and task sharing allow individuals to predict others' actions, it remains unclear how they would go from predicting another's action to choosing an appropriate complementary action at an appropriate time. This study advances our knowledge about the processes integrating self and other by revealing how quickly the temporal feedback about others' actions (165 ms) is used in anticipatory action control.

8.4 Neural implications

At this stage it is tempting to link between the present results (at least part of them) with current neuroimaging literature in social cognition. Our results might suggest that intentionality modulates the way biological motion is perceived in the human brain. On the basis of various findings (see Puce & Perrett, 2003, for review) it might be advanced that at least some of the areas associated with biological motion perception may be sensitive to the 'intentional' component carried by the observed movement. Some support to this proposal comes from the demonstration that parietal activity during action observation is modulated by the relationship between an observer and an actor (Kilner, Marchant, & Frith, 2006). In this study magneto-encephalography (MEG) was used to record cortical activity of human subjects whilst they watched a series of videos of an actor making a movement. Only when the actor was facing towards the participant, a modulation was observed in the pattern of activity elicited by action observation. This finding has been interpreted as to suggest that signals about the action of other people are filtered, allowing only the most socially relevant actions to activate a motor representation. Indeed, the parietal cortex has long been thought of as a bridge between perception and action. New evidence point at the anterior intraparietal sulcus (aIPS) of humans as a critical node within a network involved in the higher order dynamic control of action, including representation of intended action goals (Tunik, Rice, Hamilton, and Grafton, 2007). The rich connections that AIP shares with other parietal regions, as well as with the occipital and frontal cortices, place it in a strategic position for multimodal integration. Furthermore, AIP seems to be essential for the on-line control of action. In a transcranical magnetic stimulation (TMS) study, disruption in the region of aIPS leaded to impaired on-line control for reaching in a target perturbation task (Desmurget & Grafton, 2000). In a similar study, virtual lesions of aIPS disrupted goal-dependent on-line adjustments of grasp (Tunik, Frey, & Grafton, 2005). TMS-related effect during perturbed trials was contingent on the timing of the TMS pulse being locked to the occurrence of the perturbation and was not evident when TMS was delivered at large delays after or before the perturbation. These data make a convincing case that aIPS is a flexible dynamic site highly involved in dynamic control of action at a goal level. Further research will be needed to determine if goal representation in aIPS also contributes to on-line inferences about other's intentions, a mechanism presumably mediated by gaze processing.

Gaze is an important source of information of others' intentions and actions and may be an important cue from which motor intentions of others can be inferred.

Previous evidence suggests that the action observation system allows the observer to represent the agent's motor intentions by matching executed and perceived actions. This matching mechanism has been proposed not only for observed actions, but also for the coding of others' motor intentions (Iacoboni et al., 2005; Pelphrey, Morris & McCarthy, 2004). Neuroimaging evidence suggests that the STS is involved in gaze processing (Pelphrey et al., 2004; Pelphrey, et al., 2003). Given that the STS is a component of the action observation system, it might be reasonable to assume sensitivity of this system to gaze. In an event-related functional magnetic resonance imaging (fMRI) study, Pierno, Becchio, Wall, Smith, Turella and Castiello (2006) indeed revealed that the action observation system is activated even in the absence of any overtly executed action, that is, by the mere observation of gaze. This suggests that under certain conditions, gaze may be equivalent to overt hand actions.

An aspect of gaze processing, which so far has been given little attention, is the influence that intentional gaze can have on object processing. Recent evidence (Becchio, Bertone & Castiello, 2008) leads to the conclusion that gaze has the potency to transfer to the object the intentionality of the person looking at it. When considering the context of social interactions, any object falling under the gaze of others can acquire novel observer-dependent properties. Further evidence related to the observation of social interactions comes from a functional magnetic resonance imaging (fMRI) study (Pierno, Becchio, Turella, Tubaldi & Castiello, 2008) revealing that activity within an area classically involved in social cognition, the dorsal medial prefrontal cortex (dMPFC), is modulated by the gaze of the agents performing the observed action. In particular, when the actors' gaze was masked, activity within the observer's dMPFC was higher than when the actors' gaze was available. Thus, increased activation within the dMPFC seems to be associated with participants' need to extract the social meaning of the action in the absence of gaze cues. Therefore such neural site might be at the basis of the 'social action' effects reported here.

8.5 CONCLUSIVE REMARKS

The central advance of the present work is manifold. First, I have attempted to adopt a new perspective focusing on aspects which have so far received little attention. Specifically how social intentions drive reach-to-grasp movements and the context within which these actions are usually performed. Second, from a methodological perspective I have used a fairly ecological paradigm by introducing in a laboratory set up real-time social interactions – usually observed in daily living activities. Third, in theoretical terms the present work considered processes of on-line control of action under a new light. This was done by linking current advances in the methodology for recording hand kinematics and paradigms considering the presence of social interactions. As a final point, the investigation of how the intentional component defines, modulates and shapes our social actions particularly depicts the novel aspect of the present work. By investigating interactions from a kinematic point of view, it has been possible to see people 'acting social intentions' and to gain some understanding of how the motor control system integrates and manages highly cognitive problems such as sudden social requests that violate assumed procedures.

8.6 EPILOGUE

What this study adds to the growing body of evidence suggesting that individuals acting in a social context form shared action representations, is that human default mode prompt us to interact with others in a complementary way. The co-representation of human action may be an evolved biologically tuned default of the human motor system.

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APPENDIX I

The ELITE system has been designed and developed for automatic and reliable analysis of body movement in various conditions and environments. It is based on real-time processing of the TV images to recognize multiple passive markers placed on the relevant point of the body and compute their coordinates. The fast processor for shape recognition (FPSR) constitutes the core of the ELITE system (see Figure 1). It processes the TV image in real time and it uses a dedicated algorithm to recognize markers only if their shape matches a determined mask. The whole system has been designed to perform the following operations:

- to recognize the presence of markers
- to compute the X and Y coordinates of the markers centroids
- to perform the previous operations in real time
- to classify each marker on the basis of a suitable model of the body (system depending)
- to perform calibrating procedures, fitting techniques and 3D analysis by stereometric techniques when more cameras are used simultaneously
- to develop further data processing (i.e., a calculation of angular speed)

The fast processor for shape recognition (FPSR) performs cross-correlation processing on the incoming digitised TV signal, recognizes the markers and computes their coordinates. The FPSR unit is doubly connected to the interface to environment (ITE) because it not only receives the input data, but also provides the necessary signals for synchronization.

The shape detecting algorithm, essentially based on a bidimensional cross correlation between the actual digitised image and the predetermined mask, is implemented by a parallel hardware structure allowing the real time processing. The cross-correlated signal is compared to predetermined threshold value ad the over-threshold point coordinates are considered as a probable marker component. Once the threshold detection has been performed, the centroid of the over threshold point is calculated. The points over the threshold form a cluster like that shown in Figure 1, left corner. The output from the FPSR are directly the “r” couples of horizontal and vertical coordinates of the “r” markers detected which are delivered to the central processing unit (CPU).

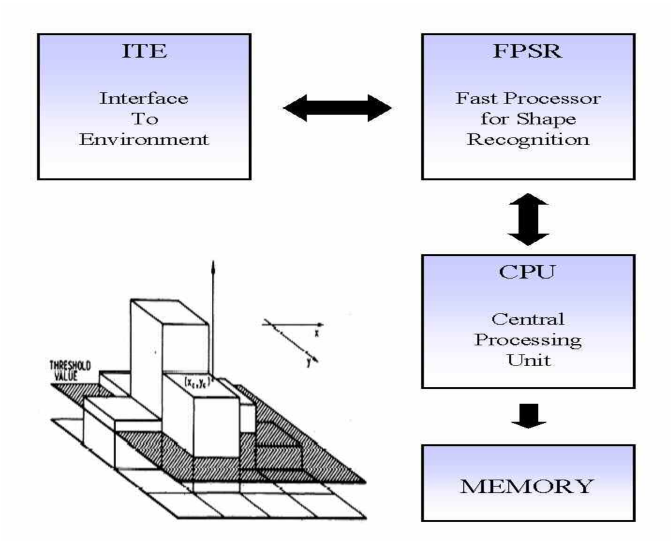


Figure 1. ELITE block diagram and (left corner) centroid calculation of the over-threshold points of the cross correlation function.

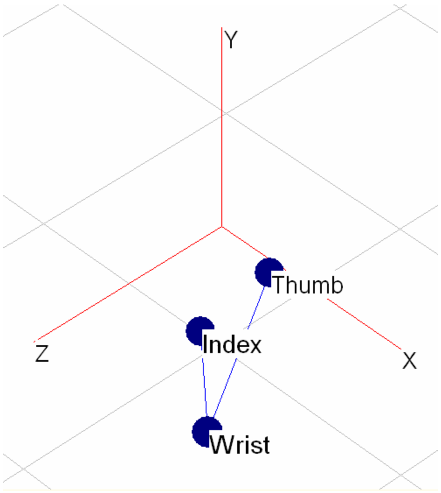
Hemispheric reflective markers are used for the following reasons:

- They can be easily fixed to the body
- Their image does not change if they rotate on their axis of symmetry
- Their images does not significantly change if they rotate on the other two axes
- The reflective material increases the contrast, thus improving recognition reliability

In order to analyse a spatial movement, the ELITE system must be made aware of all relative spatial information contained within the working volume (the space in which the movement will take place). The spatial calibration is obtained by knowing:

- The position and orientation of all TVC's (television camera) with respect to the laboratory reference system.
- The correction of optical image distortions from each TVC (linearization).
- The dimension of the working volume (3D calibration).

Figure 2 depicts the coordinate based reference system in accordance with the 'right-hand-rule'. During a movement analysis, the positive X axis represents the progression of movement. Consequently, the XY plane represents the lateral view of the motion, the YZ plane depicts frontal movements, and the XZ plane transverse movements.



X Axis The progressive movement axis

Y Axis Vertical, positive in up direction

Z Axis Transverse to the direction of movement

Figure 2. Reference system of hemispheric reflective markers within the spatial calibrated volume.

After the first-level processing, the information (marker coordinates) is transferred to the CPU in order to extract information of general interest from raw data.

APPENDIX II

The TRACKLAB programme is an interactive sequence that identifies marker trajectories obtained from an acquisition. Tracking is both a quantitative and qualitative process that assists in the rapid identification of marker position throughout the frame range of the data collection. Since a large number of markers are present during an analysis, sophisticated correlation algorithms are needed to find the correlation between the marker images from one camera to another. At the end of this procedure, a set of 3D segments is then available. The tracking process was used to identify crucial regions needing editing. The data were then filtered using a finite impulse response linear filter (transition band = 1 Hz, sharpening variable = 2, cut-off frequency = 10 Hz). Following this operation, the tangential speed of the wrist marker together with the distance between the index finger and the thumb and their tangential speed were computed. These data were used to determine the onset and offset of the movement using a standard algorithm (threshold for movement onset and offset was ~ 5 cm/s). Specifically, the onset was taken as the earliest time the adopted threshold was reached (wrist marker). The offset was taken at the latest time at which the adopted threshold was detected at the level of the thumb and index fingers markers during the hand closing phase.

APPENDIX III

Simple baseline break detection algorithm

The following is a description of the semi-automatic procedure used to determine the moment at which the hand began to deviate in the perturbed trials.

The algorithm uses the trapezoidal rule to compute the integral of an array relative to a baseline value:

n = number of samples; h = sampling interval; b = baseline value,

$n = \{a_0, a_1, ..., a_n, -1\}$

$$I(a,b,n,h) = \sum_{i=0}^{n-2}\left(\frac{(a_i - b) + (a_{i+1} - b)}{2}\right)h$$

This can be computed more efficiently as:

$$I(a,b,n,h) = \left(\frac{h}{2}\right)\left(a_0 + 2\left(-b\left(n-1\right) + \sum_{i=1}^{n-2} a_i\right) + a_{n-1}\right)$$

Beginning at trial onset, the algorithm computes the integral of a section (window) of the array, the duration of which can be modified by the user. Baseline for the integral is taken as the amplitude of the first sample (data point) of this window. The window then shifts one data point to the right and the second integral is computed.

w = window size, adjustable by user; m = multiple of a_i, adjustable by user.

$$F(a,i,n,h,w,m) = \begin{cases} 0 \le i \le n-w : \left(\frac{h}{2}\right)\left(a_{i+w-1} - 2na_i + 2\sum_{j=i+1}^{i+w-2} a_j\right) \\ n-w < i < n : a_i \\ i \ge n : a_{n-1} \end{cases}$$

The integral is evaluated for each subsequent window until the result exceeds the product of a user-determined multiple (of integral) and the integral of the first data point of the current window. With presentation of this result the user chooses to accept, adjust, or reject. New values for window duration and baseline multiple can be entered to improve the ensuing selection procedure. With rejection this sliding calculation of integral continues until the end of the array.

APPENDIX IV

Statistical results for the preliminary analyses performed on the contrasts and the dependent measure of interest for the naïve group of participants.

	Movement Duration	Amplitude Wrist Velocity	Trajectory Height	Deceleration Time	Time of Maximum Grip Aperture	Amplitude of Maximum Grip Aperture
Contrasts						
Top vs. Bottom	$F_{(1,11)} = 1.1$ $p > .05$	$F_{(1,11)} = 0.7$ $p > .05$	$F_{(1,11)} = 2.1$ $p > .05$	$F_{(1,11)} = 0.5$ $p > .05$	$F_{(1,11)} = 1.2$ $p > .05$	$F_{(1,11)} = 2.1$ $p > .05$
Slow (alone vs. passive agent)	$F_{(1,11)} = 2$ $p > .05$	$F_{(1,11)} = 2.2$ $p > .05$	$F_{(1,11)} = 0.5$ $p > .05$	$F_{(1,11)} = 1.3$ $p > .05$	$F_{(1,11)} = 0.9$ $p > .05$	$F_{(1,11)} = 0.5$ $p > .05$
Fast (alone vs. passive agent)	$F_{(1,11)} = 1.2$ $p > .05$	$F_{(1,11)} = 1.5$ $p > .05$	$F_{(1,11)} = 2.8$ $p > .05$	$F_{(1,11)} = 2.7$ $p > .05$	$F_{(1,11)} = 0.7$ $p > .05$	$F_{(1,11)} = 1.7$ $p > .05$
Fast (alone vs. competition)	$F_{(1,11)} = 18.2$, $p < .001$	$F_{(1,11)} = 10.1$, $p < .001$	$F_{(1,11)} = 11.4$, $p < .001$	$F_{(1,11)} = 25.7$, $p < .001$	$F_{(1,11)} = 8.3$, $p < .01$	$F_{(1,11)} = 7.1$, $p < .05$
Slow (alone vs. cooperation)	$F_{(1,11)} = 13.1$, $p < .001$	$F_{(1,11)} = 17.5$, $p < .001$	$F_{(1,11)} = 29.2$, $p < .001$	$F_{(1,11)} = 12.1$, $p < .001$	$F_{(1,11)} = 20.1$, $p < .001$	$F_{(1,11)} = 11.4$, $p < .01$
Cooperation vs. Slow (passive agent)	$F_{(1,11)} = 16.1$ $p < .001$	$F_{(1,11)} = 7.3$ $p < .05$	$F_{(1,11)} = 10.1$ $p < .001$	$F_{(1,11)} = 34.7$ $p < .001$	$F_{(1,11)} = 12.8$ $p < .001$	$F_{(1,11)} = 8.1$ $p < .05$
Competition vs. Fast (passive agent)	$F_{(1,11)} = 38.7$ $p < .001$	$F_{(1,11)} = 44.4$ $p < .001$	$F_{(1,11)} = 56.7$ $p < .001$	$F_{(1,11)} = 31.3$ $p < .001$	$F_{(1,11)} = 9.6$ $p < .001$	$F_{(1,11)} = 6.1$ $p < .05$
Cooperation vs. Competition	$F_{(1,11)} = 70.4$ $p < .001$	$F_{(1,11)} = 48.6$ $p < .001$	$F_{(1,11)} = 10.1$ $p < .001$	$F_{(1,11)} = 37.2$ $p < .001$	$F_{(1,11)} = 27.3$ $p < .001$	$F_{(1,11)} = 42.1$ $p < .001$

APPENDIX V

Mean, standard deviations (in parentheses) and statistical values for the considered dependent measures for Experiments I, II, III and IV. Asterisks indicate significant comparisons.

	Experiment I		Experiment II		Experiment III		Experiment IV			
							Gaze		No Gaze	
	Unperturbed	Perturbed	Unperturbed	Perturbed	Unperturbed	Perturbed	Unperturbed	Perturbed	Unperturbed	Perturbed
Reach-to-grasp phase										
Time maximum trajectory curvature (%)	47 (6)	43* (5)	51 (5)	50 (6)	51 (4)	51 (7)	52* (3)	48 (5)	47 (4)	46 (7)
Maximum deviation (mm)	15 (9)	-18 (7)	20 (8)	6 (10)	23 (12)	9 (15)	23 (9)	-20 (13)	22 (7)	4 (9)
Place phase										
Time maximum trajectory height (ms)	438 (61)	462* (71)	401 (82)	428 (82)	378 (57)	383 (86)	378 (52)	390* (72)	359 (51)	381* (61)
Amplitude maximum trajectory height (mm)	142 (19)	148* (25)	132 (22)	140 (29)	139 (11)	142 (15)	122 (23)	125* (26)	139 (18)	142* (20)