



Different action patterns for cooperative and competitive behaviour [☆]

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Received 19 October 2005; revised 23 December 2005; accepted 17 January 2006

Abstract

The aim of the present study is to elucidate the influence of context on the kinematics of the reach-to-grasp movement. In particular, we consider two basic modes of social cognition, namely cooperation and competition. In two experiments kinematics of the very same action – reaching-to-grasp a wooden block – were analyzed in two different contexts provided by a cooperative task and competitive task. For the ‘cooperation’ tasks two participants were required 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. In accordance with evidence from neuroimaging, developmental and social psychology our results suggest the existence of motor patterns which reflect the intention to act in a social context.

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Keywords: Competition; Cooperation; Kinematics; Reach-to-grasp; Humans; Social cognition

[☆] This manuscript was accepted under the editorship of Jacques Mehler.

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1. Introduction

A key question for psychologists concerns the mechanisms that allow for skilful social interactions. Although enormous advances in our understanding of the links between the mind, the brain and behaviour have been made in the last few decades, these have been largely based on studies in which people are considered as strictly isolated units. For example, studies might typically examine how the kinematics of the reach to grasp movement vary on the basis of specific object properties (e.g., fragility, size and weight) without the intention to use that object to interact with other people (for review see Castiello, 2005). The challenge is to understand whether the same action performed in different contexts acquires different meanings and reflects different intentions. Is this difference in attitude reflected in movement kinematics?

In this paper, we tackle this important challenge by investigating the mechanisms that underlie the same action carried out in different social contexts. In particular, we ask whether it is possible to differentiate the kinematics of an action performed by an agent acting in isolation from the kinematics of the very same action performed with a social intention. Further, we examine whether it is possible to differentiate, within a social context, between the kinematics of two basic modes of social cognition: cooperative or competitive action patterns. If the kinematics are sensitive to context, as we here hypothesize, then a difference in kinematics should be found between an action performed in the context of a cooperative task and the same action performed as part of a competitive interaction.

Available evidence indicates that both cooperation and competition involve a specific, and often distinct, psychological and cortical mechanisms. Research in social psychology has demonstrated that in cooperation the outcomes of the perceiver and the other person rely on their collaborative accomplishments, whereas in competition the outcomes of the perceiver are inversely related to those of their opponent (Vonk, 1998). Further, both cooperative and competitive behaviours involve executive functions and mentalising abilities, but with some significant differences. For example, although in ‘mentalising’ terms both cooperative and competitive interactions involve predicting the behaviour of the other actor, anticipating the behaviour of the other taking into account her independent mental state is more salient when social partners are in competition than when they are cooperating. In terms of ‘executive functions’ there is evidence from recent developmental work to suggest that self-other monitoring abilities, i.e., the ability to guide action in concert with both internal intentions and those of others, differs between cooperative and competitive contexts (Decety & Sommerville, 2003; DeCremer & Stouten, 2003; Sommerville & Hammond, 2003). For example, Sommerville and Hammond (2003) demonstrated that preschool children were significantly worse at recalling the agent of an action when they cooperated with an experimenter towards building a toy vs when they took turns working independently of the experimenter to build the toy.

Recent work has examined the neural substrates underlying cooperation and competition in humans. In one fMRI study, participants played an economic trust game with another person following a fixed probabilistic strategy. The results showed a significant activation of the right medial prefrontal cortex during the

interaction (McCabe, Houser, Ryan, Smith, & Trouard, 2001). Decety, Jackson, Sommerville, Chaminade, and Meltzoff (2004) studied individuals playing a specially designed computer game, according to a set of predefined rules, either in cooperation with or in competition against another person. Both cooperation and competition stances resulted in activation of a common frontoparietal network subserving executive functions. However, the orbitofrontal cortex was found to be selectively activated during cooperation whereas the inferior parietal and medial prefrontal cortices were selectively activated during competition. Thus, these findings highlight brain regions which play a role in the distinction between self-produced actions and actions generated by others (Farrer & Frith, 2002; Meltzoff & Decety, 2003).

Despite this considerable corpus of work on cooperation and competition to date, so far no experimentation has been conducted to elucidate how these different mind sets and brain structures translate into *measurable behaviour*. In the present study, we use kinematic recordings to investigate possible behavioural differences for contrasting social attitudes. To this end, the kinematics of the very same action – reaching-to-grasp a wooden block – were analyzed in two different contexts, provided by a cooperation task and a competition task. The ‘cooperation’ task, the reach-to-grasp action prepared a cooperative interaction: participants were required to reach and grasp their respective objects and to cooperate so as to join the two objects in the middle of the working surface. The ‘competition’ task was similar to the cooperation task, except that, once grasped their respective objects, the two participants had to compete to place them first in the middle of the working surface. In order to identify the particular kinematic pattern denoting a movement preparing a social interaction with respect to a movement executed in isolation, two ‘single-agent’ conditions were included. In one condition subjects were requested to reach and grasp and move to the centre the stimulus at a natural speed. In the other condition subjects were requested to reach and grasp the stimulus as fast as possible. Given previous report of reach-to-grasp kinematics for slow-natural (e.g., Jakobson & Goodale, 1991) and fast movements (Wing, Turton, & Fraser, 1986), we expected substantial kinematical differences between the two conditions. What we were interested in was to compare kinematics of the natural-speed reach-to-grasp performed by a single participant in isolation and the cooperative condition, in which a presumably slow careful movement is required. Likewise, we investigated possible differences between the fast-speed single-agent condition and the competitive condition. Finally, to exclude that possible differences may have been due simply to the presence of another person, we included two ‘passive-observer’ conditions: these conditions were similar to the single-agent natural and fast speed conditions previously described, except that each subject performed the action in the presence of another person who simply observed the scene.

It should be noted that in all conditions the kinematic analysis was restricted to the initial reach-to-grasp movement. In the single agent conditions this movement preceded the individual action of placing the object on the table; in the cooperative and the competitive tasks it was preparatory to the successive social interaction, being not part of the interaction itself. Thus, if a difference in the kinematics of the reach-to-grasp movements among conditions is revealed, then this difference might be ascribed to the agent’s attitude.

2. Experiment 1

2.1. Methods

2.1.1. Subjects

Sixteen subjects (13 females–3 males, ages 19–40) took part in the experiment. All participants were right-handed, reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment. They were randomly assigned in eight pairs and each pair attended one experimental session of 1 h duration.

2.1.2. Stimuli

The stimuli were a pair of blue wooden blocks ($4 \times 4 \times 8$ cm) with a white semi-circle drawn on their top surface. When the two objects were joined together a complete white circle would appear by the union of their top surfaces. The stimuli 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 (Fig. 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 (Fig. 1a).

2.1.3. Procedures

The experiment was conducted under normal lighting conditions. Two participants were seated opposite to each other in front of a working surface (122×60 cm). Before each trial, the right hand of each participant rested on a starting pad (green velvet cloth 6×4 cm) with the index finger and the thumb gently opposed. The starting pad was attached 3 cm away from the edge of the table in a midsagittal position 15 cm away from the midsection (Fig. 1a). Participants were requested to start the action after a tone (880 Hz/200 ms) was presented.

Subjects were tested in six experimental conditions. Each subject performed 10 trials for each condition.

1. *Single-agent: Natural speed.* 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: Fast speed.* 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.
3. *Passive observer: Natural speed.* This condition was similar to the natural speed – alone condition except that each participant performed the action in the presence of another participant simply observing the scene.
4. *Passive observer: Fast speed.* This condition was similar to the fast speed – alone condition except that each participant performed the action in the presence of another participant simply observing the scene.

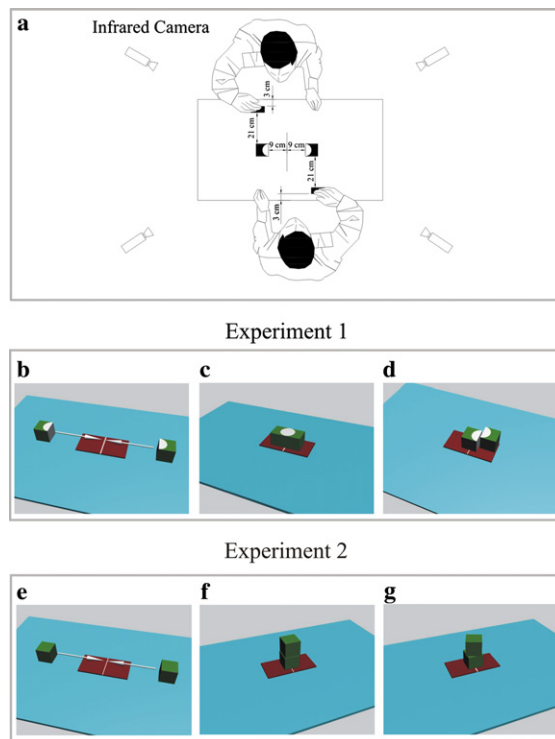


Fig. 1. Experimental set up for Experiment 1 and Experiment 2. (a) Subjects' posture, the positioning of the stimuli and the positioning of the infrared cameras. (b) Direction of movement. (c and d) Cooperation task and competition task, respectively, for Experiment 1. Note that for the cooperation task both objects are brought in the middle of the table, whereas in the competition task participants compete so as to put their object in the middle of the table first. (e) Direction of movement. (f and g) Cooperation task and competition task, respectively, for Experiment 2. 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).

5. *Cooperation*. Every pair of participants performed the cooperation task. Two participants seated opposite to each other were required to reach for their respective objects and bring it towards the middle of the table as to form a complete white circle (Figs. 1b and c). Both participants were requested to start the action at the time the start signal was presented.
6. *Competition*. This condition was similar to the cooperation condition except that the participant had to compete as to put their respective object in the middle of the table first (Fig. 1d). Both participants were requested to start the action at the time the start signal was presented.

2.1.4. Recording techniques

The ELITE motion analysis system (Bioengineering Technology & Systems [B T S]) was used to record movements. Reflective passive markers (0.4 cm diameter) were attached on the (a) wrist: radial aspect of the distal styloid process of the radius; (b) index finger: radial side of the nail; (c) thumb: ulnar side of the nail. The wrist marker was used to measure the reaching component of the action. The finger and thumb markers were used to measure the grasp component of the action. When two subjects were acting simultaneously (cooperation and competition conditions) kinematics were computed for both subjects. Four infrared cameras (sampling rate 100 Hz) placed 120 cm away from each of the four corners of the table (see Fig. 1a) 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.

2.1.5. Data processing

An in-house software package was used to analyse the data. The dependent measures specifically relevant to test the experimental hypothesis were (a) movement time; (b) the amplitude of wrist peak velocity; (c) the time from peak velocity to the end of the movement (deceleration time); and (d) the time of maximum grip aperture. These variables were chosen because they have been proved to be sensitive to variations in movement speed (Wing et al., 1986). For example, movement time is shorter, amplitude of wrist peak velocity is higher and deceleration time is longer for fast than for natural movements. This kinematic distinction is important because we expect cooperation and competitive tasks to differ in terms of speed. Given that we expect the kinematic patterns for cooperation and competition to differ with respect to movement speed, possible kinematic differences may be better understood when the occurrence of kinematic events are expressed in terms relative to the overall movement time. Following this assumption, each temporal value of the reach and grasp component was normalised as a percentage of movement time (relative values). Analyses of spatial trajectories included the amplitude of the maximum height of the wrist trajectory from the working surface.

2.1.6. Data analysis

Although the subjects' movement was performed in two steps, reaching and grasping the object and bringing the grasped object to a specific place, kinematic analyses were restricted to the phase leading up to the grasping of the object. This was done so that the possible differences could be attributed to the mental set of the agent as opposed to the dynamics of the interaction itself.

The means for each kinematic parameter of interest for the six experimental conditions were determined for each participant. For each dependent variable, the means for each participant were then entered into a one-way within-groups multivariate analysis of variance (MANOVA). The within subjects factor was the type of condition (alone/natural, alone/fast, presence natural, presence/fast, cooperation

and competition). Preliminary analyses were conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance–covariance matrices and multicollinearity, with no serious violations noted. Where necessary, post hoc Sheffe tests were conducted comparing the mean values of interest in order to specify the nature of the effects. All tests of significance were based upon an α level of 0.05. A series of contrasts between conditions were planned (Bonferroni corrected):

1. *Single-agent natural speed vs single-agent fast speed.* To identify differences in kinematic patterning for natural and fast speed movements performed by a single participant.
2. *Single-agent natural speed vs passive observer natural speed.* To test for possible differences in kinematic patterning due to the presence of a ‘passive’ observer.
3. *Single-agent fast speed vs passive observer fast speed.* To test for possible differences in the fast reach-to-grasp kinematic patterning due to the presence of a ‘passive’ observer.
4. *Single-agent natural speed vs cooperation.* To test for possible differences in kinematic patterning for a slower natural reach-to-grasp movement when the two participants were engaged in the cooperation task than when each of them performed the natural action alone.
5. *Passive observer natural speed vs cooperation.* To test for the possible difference between the presence of an ‘acting’ (cooperating) and a ‘passive’ (observing) agent.
6. *Single-agent fast speed vs competition.* To test for possible differences in kinematic patterning for a fast reach-to-grasp movement when the two participants were engaged in the competition task than when each of them performed the fast action alone.
7. *Passive observer fast speed vs competition.* To test for the possible differences in kinematic patterning between the ‘acting’(competing) and the ‘passive’ agent conditions for a fast movement.
8. *Competition vs cooperation.* To test for possible differences in kinematic patterning between the cooperation and the competition tasks.

Correlation analyses were also conducted to explore whether there was a linear relationship within the movements of each couple in the ‘cooperation’ and the ‘competition’ conditions. In particular, we investigated the existence of such relationship for two key kinematic parameters using Pearson Product-moment correlation coefficient: the time to maximum peak height trajectory and the time of maximum grip aperture. These two parameters were chosen because they might reflect an index of the degree of cross-talk between the two agents during the social action. Time to maximum grip aperture is the moment at which the fingers start to close on the object. Time to maximum peak height signifies the time in which the arm (and the hand) starts to land on the object. Thus, it might well be that during the cooperation task the two agents by means of on-line monitoring tend to correlate these two precise moments in time. In competition, it might well be that either the fast action or

the nature of the ‘competitive’ social action do not allow for such correlation to take place.

2.2. Results

The results from the MANOVA indicated that the main factor type of condition was significant for the following dependent measures: movement time [$F(5,85) = 47.19, p < 0.0001$; see Fig. 2a]; the amplitude of maximum peak velocity [$F(5,85) = 42.90, p < 0.0001$; see Fig. 2b]; deceleration time expressed as a percentage of movement time [$F(5,85) = 3.76, p < 0.01$; see Fig. 2c]. Below we describe the results of the planned contrasts.

2.2.1. The effects of speed: Single-agent natural vs fast

In line with previous reports (Wing et al., 1986) movement time was longer ($p < 0.0001$) for the condition in which single participants reached for the object at a natural speed (870 ms), than when they performed the movement at fast speed (550 ms). For fast movements maximum velocity was lower (1046 vs 1521 mm/s; $p < 0.0001$) and the percentage of time spent in deceleration was shorter (45% vs 53%; $p < 0.0001$), in the ‘single-agent natural speed’ condition than in the ‘single-agent fast speed’ condition. These results highlight differences in the kinematic patterning for natural and fast speed movements performed by a single participant.

2.2.2. Comparing the single-agent conditions with the passive observer, cooperation and competition conditions

When comparing the natural and the fast actions performed by a single agent with the same actions performed in the presence of a ‘passive’ observer no differences in kinematic patterns were found. This signifies that the presence of a person simply observing the scene does not change the ‘natural’ and ‘fast’ speed kinematic patterning of the agent performing the task. However, comparing the natural actions performed by a single agent with the ‘cooperation’ condition, in which a similar careful and natural action was performed, but subtended by a social attitude, showed that the percentage of time spent during the deceleration phase of the movement was longer for the cooperation than for the single-agent natural speed condition (64% vs 53%; $p < 0.0001$; see Fig. 2c). This result suggests that subjects needed extra time to synchronise their movements during the cooperative interaction. When comparing the fast actions performed by a single agent with the ‘competition’ condition, the expressed velocity was lower for the single-agent condition than for the competition condition (1521 vs 1979 mm/s, $p < 0.0001$; see Fig. 2b). All in all, these results suggest that social actions performed with social attitude trigger a kinematic patterning which is different from the same actions performed individually.

2.2.3. Cooperation vs competition

The comparison between the kinematic patterning for cooperation and competition revealed that acting in a cooperative manner elicited a slower movement time than acting in competitive manner (455 vs 809 ms; $p < 0.0001$; see Fig. 2a).

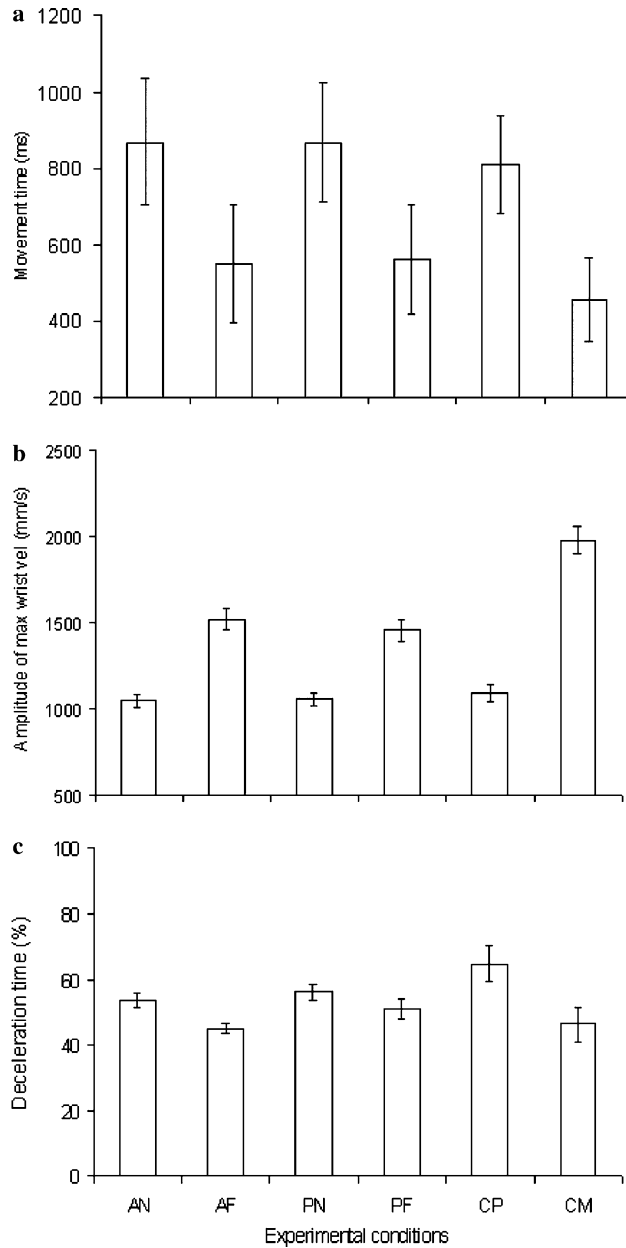


Fig. 2. Movement time (a), amplitude of maximum peak velocity (b) and deceleration time (c) for the different experimental conditions in Experiment 1. AN, single-agent natural; AF, single-agent fast; PN, natural movement in the presence of a 'passive' observer; PF, fast movement in the presence of a passive observer; CP, cooperation and CM, competition.

Consequently, a lower speed was exerted for the cooperation than for the competition task (1093 vs 1979 mm/s, $p < 0.0001$; see Fig. 2b). Importantly, this comparison also revealed that in relative terms, when differences in movement duration (fast, natural) were normalised, deceleration time was longer for cooperation than for competition (65% vs 46%, $p < 0.0001$; see Fig. 2c). The longer time spent in decelerating for the cooperative task suggests that performing an action towards an object with the intention to precisely locate it in a predetermined way for the purpose of cooperation produced a slower feedback guided decelerative phase. In contrast, as reflected by the very short deceleration time, the competition task seemed to elicit a more ballistic type of movement for which no great care at the level of honing phase was required.

2.2.4. Correlational analyses

For both the ‘cooperation’ and the ‘competition’ conditions no significant correlations for the time to maximum trajectory height and the time of maximum grip aperture were found (against the prediction of on line monitoring during the performance of these two tasks). These results applied to all couples.

2.3. Discussion

As expected the amplitude and temporal aspects of the considered kinematical parameters varied depending whether the action was performed naturally or as fast as possible. In particular, movement time was longer, the amplitude of peak velocity lower, deceleration time prolonged for movements performed at natural speed than at faster speed (e.g., Wing et al., 1986). Thus, we were able to identify baseline patterns which provide a mean of comparison with the movements performed in the presence of another person simply observing, cooperating or competing.

Importantly, the critical comparisons suggest that the context influences the kinematics of the actions, so that the kinematics of a reach-to-grasp movement performed in isolation are different from the kinematics of the same action directed towards a subsequent social interaction. For example, performing a cooperative reach-to-grasp action entails a longer deceleration time than does a natural reach-to-grasp action performed by a single agent. An opposite pattern is found when comparing competitive reach-to-grasp actions with single-agent fast actions. In particular, subjects show a higher peak velocity during competition than when they perform the fast action in isolation. All in all, these observations suggest that the social interaction subsequent to the grasping of the object affects how the object is reached for.

Furthermore, differential kinematical patterns for cooperation and competition emerge: these patterns significantly differ from those obtained for actions performed in the presence of a ‘passive’ observer. An unexpected result was the lack of correlation for key kinematic landmarks between the movements performed by the two agents during the cooperation task. We would have expected some sort of online control by the two agents on their respective action or of the action performed by the other so as to successfully complete the task. We suspect that this lack of

correlation might be due to two factors. First, for the cooperation task each subject could perform her action as part of a single independent action. In particular, being predetermined where to position the object, subjects may not need to monitor the action performed by the other subject in order to accomplish the task requirements. Second, the additional precision requirement of forming a circle after having brought the object to a specific location for the cooperation condition (which was not present for the other ‘natural’ conditions) might be responsible for the lack of cooperation effects. We tested these possibilities in Experiment 2 by enhancing the need for temporal synchronicity and by reducing the difference in additional precision requirements for the cooperation condition.

3. Experiment 2

In order to enhance cooperation in the present experiment for the ‘cooperation’ task participants were required to reach and grasp for their respective objects and to form a tower putting one object on top of the other. Crucially, the agent which was requested to put the object at the top had to wait until the object at the bottom was properly placed. The ‘competition’ task was similar to the cooperation task, except that, once grasped their respective objects, the two participants had to compete to place them first as the bottom part of the tower. If increasing the need for synchronicity during cooperation requires more on-line monitoring of the other’s action, we expect a greater level of correlation for key kinematic parameters. Further, we also expect to confirm distinctive kinematic patterns when comparing the ‘cooperation’, ‘competition’ and single agent conditions.

3.1. Methods

3.1.1. Subjects

Sixteen participants (13 females–3 males, ages 19–32) took part in the experiment. As in Experiment 1, all participants were right-handed, reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment. They were randomly assigned in eight pairs and each pair attended one experimental session of 1 h duration.

3.1.2. Stimuli

The stimuli were the same as those utilised in the previous experiment except that no white half circle was present on the object (see Fig. 1e).

3.1.3. Procedures

The procedures were similar as those for Experiment 1 except that participants were required to reach and grasp for their respective objects and to either cooperate so as to form a tower by putting one object on top of the other, or compete to be the first to place their object on the bottom (Fig. 1f).

3.1.4. Data processing

Data processing was the same as for Experiment 1.

3.1.5. Experimental conditions

Subjects were tested in 10 experimental conditions. Each participant performed 10 trials for each condition. For each condition every trial commenced with an acoustic signal (880 Hz/200 ms).

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 participant condition except that each participant performed the action in the presence of another participant observing the scene.
6. *Passive observer: Natural speed top.* This condition was similar to the natural speed top – single participant condition except that each participant performed the action in the presence of another participant observing the scene.
7. *Passive observer: Fast speed bottom.* This condition was similar to the fast speed bottom – single participant condition except that each participant performed the action in the presence of another participant observing the scene.
8. *Passive observer: Fast speed top.* This condition was similar to the fast speed top – single participant condition except that each participant performed the action in the presence of another participant observing the scene.
9. *Cooperation bottom/top condition.* The two participants seated opposite to each other and were required to reach for their respective objects. One subject was instructed to put it on the bottom whereas the other subject was instructed to put it on the top so as to form a tower (Fig. 1e). The top/bottom order was counterbalanced across subjects.
10. *Competition condition.* This condition was similar to the cooperation condition except that the subjects had to compete as to put first the respective object in the bottom of the tower (Fig. 1f).

3.1.6. Data analysis

The means for each kinematic parameter of interest (see ‘data analysis’ section in Experiment 1) obtained for the 10 experimental conditions were determined for each participant. First of all we performed a series of one way analyses of variance (ANOVA) to check for top/bottom differences for each kinematic parameter for each condition. The reason for this was that the movement after the object was grasped was not an issue in the present paper. Further, the changes in elevation were not as such as to determine strong changes in maximum height of the trajectory. The results indicated that no top/bottom differences in key kinematic parameters were found (all $p_s > 0.05$). Consequently top/bottom data were collapsed and a multivariate repeated measures analyses (MANOVA) was conducted. The same planned contrasts as in Experiment 1 were performed. As for Experiment 1 correlation analyses were conducted for the time of maximum trajectory height and the time of maximum grip aperture using Pearson Product-moment correlation coefficient.

3.2. Results

The results from the MANOVA indicated that the main factor type of condition was significant for the following dependent measures: movement time [$F(5,85) = 43.06$, $p < 0.0001$]; the amplitude of peak velocity [$F(5,85) = 28.36$, $p < 0.0001$]; deceleration time [$F(5,85) = 9.05$, $p < 0.02$]; the amplitude of maximum trajectory height [$F(5,85) = 56.98$, $p < 0.0001$]; and time of maximum grip aperture [$F(5,86) = 10.07$, $p < 0.001$]. The results of the planned contrasts are reported below.

3.2.1. The effects of speed: Single-agent natural vs fast

The results presented in this section mirrored those obtained for Experiment 1. Movement time was shorter (501 vs 697 ms, $p < 0.0001$; see Fig. 3a), the amplitude of peak velocity was higher (1521 vs 1046 mm/s, $p < 0.001$; see Fig. 3b) and the deceleration time was shorter (45% vs 53%, $p < 0.001$; see Fig. 3c) in fast vs normal-speeded movements.

3.2.2. Comparing the single-agent conditions with the passive observer, cooperation and competition conditions

Movement time was longer for the condition in which single participants reached for the object at a natural speed than for the cooperation task (695 vs 616 ms, $p < 0.05$; see Fig. 3a). Moreover, movement time was longer for the condition in which single participants reached for the object at a fast speed than for the competition task (501 vs 442 ms, $p < 0.001$; see Fig. 3a). The amplitude of the maximum height of the wrist trajectory from the working surface was lower for the competition task than for fast reaches performed by the single agent (86 vs 107 mm, $p < 0.01$; see Fig. 4a). A similar decrease for the maximum height of the wrist trajectory was evident for the cooperation task than for natural reaches performed in the single-agent condition (109 vs 116 mm, $p < 0.01$; see Fig. 4a).

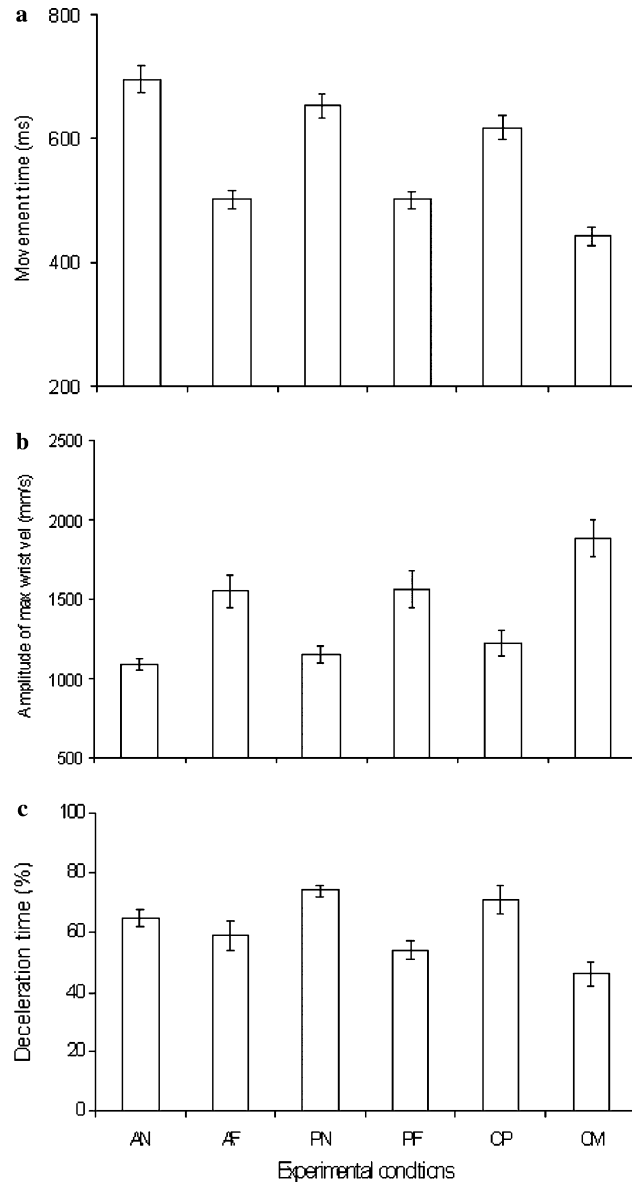


Fig. 3. Movement time (a), amplitude of maximum peak velocity (b) and deceleration time (c) for the different experimental conditions in Experiment 2. AN, single-agent natural; AF, single-agent fast; PN, natural movement in the presence of a 'passive' observer; PF, fast movement in the presence of a passive observer; CP, cooperation and CM, competition.

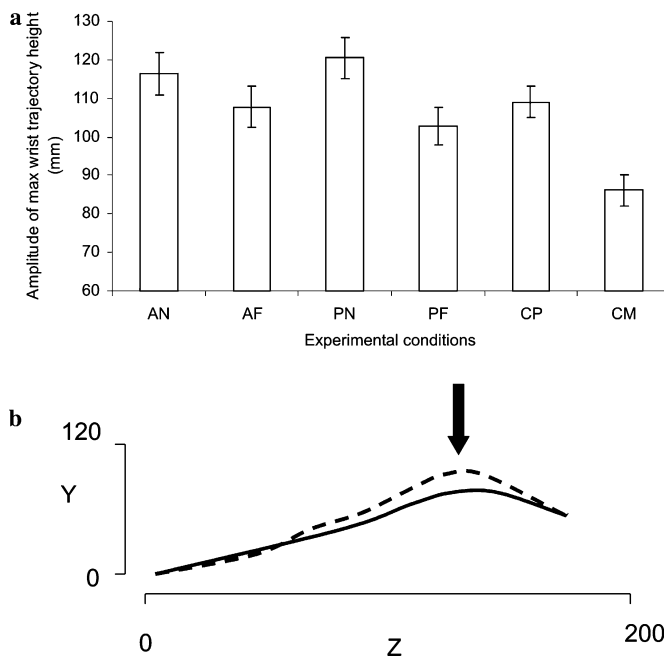


Fig. 4. (a) Amplitude of maximum wrist height for the different experimental conditions in Experiment 2. AN, single-agent natural; AF, single-agent fast; PN, natural movement in the presence of a 'passive' observer; PF, fast movement in the presence of a passive observer; CP, cooperation and CM, competition. (b) Representative examples of trajectories of the reaching component on the sagittal plane for the cooperation (dashed line) and competition (solid line) conditions. Values on the axis are in millimeters (ms). Axis z = sagittal axis; axis y = vertical axis. The arrow indicates the point of maximum trajectory height. Please note that there is no contact with the target because the marker is placed on the wrist.

These results for the spatial trajectories indicate that during social actions the arm trajectory straightened with respect to movements performed in isolation.

3.2.3. Cooperation vs competition

As for Experiment 1 this comparison revealed that for competition movement duration was shorter than for cooperation (442 vs 617 ms; $p < 0.0001$; see Fig. 3a). There was a concomitant lower speed for cooperation than for competition (1222 vs 1881 mm/s, $p < 0.0001$; see Fig. 3b). Importantly also for Experiment 2 the deceleration phase of the movement was shorter for competition than for cooperation (46% vs 71%, $p < 0.001$; see Fig. 3c) indicating that independently from speed the cooperative action was planned to employ a longer and more careful deceleration phase. Differences in the planning of these two social actions may also emerge from the spatial trajectory results. The maximum height from the table surface of the wrist trajectory was lower for competition than for the cooperation (86 vs 109 mm, $p < 0.01$; see Fig. 4a). This result may be ascribed to the fact that during competition there is a need to arrive first on the object

and to put the object at the bottom of the tower. To gain time, participants clearly tried to maintain the wrist as close as possible to the table surface (see Fig. 4b).

3.2.4. Correlational analyses

For the cooperation task all couples showed significant correlation for the time to maximum trajectory height and the time of maximum grip aperture (see Table 1). For the competition task no significant correlations for the same parameters were found for all couples. These findings provide a strong indication that the cooperation task induced the agents to coordinate the temporal aspects of key kinematic landmarks so as to fulfil the ‘social’ task requirement.

3.3. Discussion

The results obtained in Experiment 2 confirm the pattern of data obtained in Experiment 1 showing differential kinematical patterns depending on the context of the action. However, in contrast to Experiment 1 we found a high level of correlation for key kinematic landmarks in the movements performed by the two agents during the cooperation task. This latter result suggests an ability to calibrate one’s own action on the basis of the action performed by another person to achieve the overarching goal of the coordinated action. This result also suggests that for this ability to emerge task constraints which force temporal contingency have to be present. However, this may not definitely prove that coordination was social in nature because it is possible to coordinate with non-human objects such as a pendulum. Further experimentation is needed to fully explore this possibility.

Conceptually, the difference between the results of the two experiments may be interpreted as the difference between a task simply requiring the motivation to cooperate and a task requiring both cooperation and temporal coordination. In particular, two key kinematical parameters, the time of maximum trajectory height and the time of maximum grip aperture, were correlated. Correlation at this points in time – when the arm starts to land on the object and the hand starts to close on the object –

Table 1
Pearson correlations within the eight couples cooperating in respect to time of max grip aperture (MGA) and the time of maximum trajectory height (MTH) for Experiment 2

Subject pair	Time to MGA	Time to MTH
1–2	.75	.87
3–4	.82	.92
5–6	.88	.79
7–8	.98	.85
9–10	.79	.92
11–12	.95	.88
13–14	.86	.78
15–16	.80	.77

Note. All significant at the 0.01 level.

indicates that agents grasping the object with a cooperative attitude are already acting in synchrony. In this respect, it is worth noting that coordination precedes the inter-action phase (in which the objects are drawn together in the middle of the workspace): actions executed in preparation of a future joint action are already coordinated.

4. General discussion

In this study, we investigated the influence of context on the kinematics of the reach-to-grasp movement. In line with our predictions, the results showed different kinematic patterns for single independent actions and actions preparing for a subsequent social interaction. We attribute this difference to the fact that actions are planned differently depending on the global intention underlying them.

In terms of intention, these results may be interpreted as evidence of the influence of *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, is concerned with why one has decided to grasp that object (Searle, 1983). Here, we demonstrate for the first time that prior intentions are reflected in the kinematics, so that actions embedded in different contexts, triggered by different prior intentions, show different kinematic characteristics. In particular, there would be specific kinematic patterns connoting cooperative and competitive prior intentions. In this interpretation, reach-to-grasp actions executed in the context of cooperative and competitive tasks cannot be simply described as natural or fast movements. This is because they are motivated by specific prior intentions. Beyond a speed requirement – the cooperative task requires a slow careful action, the competitive task a fast movement – the kinematics of the reach-to-grasp reflect the specific nature of the task.

These conclusions must be viewed with caution, however. For one, it may be that motivational factors play a role. For example, if subjects were strongly encouraged to be fast by receiving a reward, they might show the same kinematics as for the competitive condition. For another, it might also be appropriate to characterize the difference between the social and non-social conditions as arising from the need to coordinate behaviour with external timing signals in the social conditions, independent of whether these were produced by a human or not (though this may hold only for the cooperative condition).

A further issue is concerned with whether these differences simply reflect the motor constraints imposed by tasks. It seems possible that the cooperative and competitive actions may require different control strategies, either taking into account the fine structure of the partner's movements or not. Movements with the same start and end-points, and even following the same trajectories can be controlled by completely different motor control strategies (e.g., using open vs closed loop control), and this possibility cannot be excluded here.

However, attributing kinematic differences to prior intentions does not exclude the implementation of different motor strategies; indeed, it seems to imply it. To elaborate, if prior intentions shape the kinematics of action, then it would be reasonable to assume that the action is guided by different motor strategies. For example, it is plausible that reaching to and grasping an object with a cooperative intent leads to a motor strategy which is different from the motor strategy used to reach towards and grasp an object with a competitive intent.

Among other things, this could explain how when observing other people acting we are often able to say not only *what* they are doing, but also why, i.e., the prior intention motivating their action. Recently, Iacoboni et al. (2005) investigated the neural mechanism underlying this specific ability. Using functional magnetic resonance imaging, they found that the so-called mirror system (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996) – previously thought to be involved in action recognition only – is also involved in understanding the prior intentions of others, being sensitive to the context in which the action is embedded.

The explanation of this finding – unexpected on the basis of previous work on mirror neurons (Jacob & Jeannerod, 2005) – has so far remained problematic. The question is how a system which provides an observer with the understanding of perceived actions by means of motor simulation is also able to code for prior intentions. The present results may provide a plausible answer by showing that prior intentions are reflected in the kinematics of action. In terms of action observation, they may account for the evidence that a system built for the recognition of action and sensitive to kinematic information (Tai, Scherfler, Brooks, Sawamoto, & Castiello, 2004), is also sensitive to prior intentions and context.

In conclusion, we have identified new conditions for the study of the mechanisms involved in the control of action. In particular, the present study demonstrates that the planning and execution of a goal directed action is modulated with respect to the prior intention of the agent. The adoption, on the basis of the task demands, of a specific prior intention (individual vs social, cooperative vs competitive) translates into an identifiable, measurable kinematic pattern which, even during the planning phase, is different from the kinematic pattern of the same action motivated by a different intention.

Acknowledgements

This work was supported by grants from ESRC and Ministero dell'Istruzione, dell'Università e della Ricerca (MIUR).

References

- Castiello, U. (2005). The neuroscience of grasping. *Nature Reviews Neuroscience*, 6, 726–736.
- Decety, J., & Sommerville, J. A. (2003). Shared representations between self and others: A social cognitive neuroscience view. *Trends in Cognitive Science*, 7, 527–533.

- Decety, J., Jackson, P. L., Sommerville, J. A., Chaminade, T., & Meltzoff, A. N. (2004). The neural bases of cooperation and competition: An fMRI investigation. *NeuroImage*, *23*, 744–751.
- DeCremer, D., & Stouten, J. (2003). When do people find cooperation most justified? The effect of trust and self – other merging in social dilemmas. *Social Justice Research*, *16*, 41–52.
- Di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (1992). Understanding motor events: A neurophysiological study. *Experimental Brain Research*, *91*, 176–180.
- Farrer, C., & Frith, C. D. (2002). Experiencing oneself vs another person as being the cause of an action: The neural correlates of the experience of agency. *NeuroImage*, *15*, 596–603.
- Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain*, *119*, 593–609.
- Iacoboni, M., Molnar-Szakacs, I., Gallese, V., Buccino, G., Mazziotta, J. C., & Rizzolatti, G. (2005). Grasping the intentions of others with one's own mirror neuron system. *PLoS Biology*, *3*, e79.
- Jacob, P., & Jeannerod, M. (2005). The motor theory of social cognition : A critique. *Trends in Cognitive Sciences*, *9*, 21–25.
- Jakobson, L. S., & Goodale, M. A. (1991). Factors affecting higher-order movement planning: A kinematic analysis of human prehension. *Experimental Brain Research*, *86*, 199–208.
- McCabe, K., Houser, D., Ryan, L., Smith, V., & Trouard, T. (2001). A functional imaging study of cooperation in two-person reciprocal exchange. *Proceedings of the National Academy of Sciences of the United States of America*, *98*, 11832–11835.
- Meltzoff, A. N., & Decety, J. (2003). What imitation tells us about social cognition: A rapprochement between developmental psychology and cognitive neuroscience. *Philosophical Transactions of the Royal Society, London: Biological Sciences*, *358*, 491–500.
- Rizzolatti, G., Fadiga, L., Gallese, V., & Fogassi, L. (1996). Premotor cortex and the recognition of motor actions. *Cognitive Brain Research*, *3*, 131–141.
- Searle, J. (1983). *Intentionality: An essay in the philosophy of mind*. New York: Cambridge University Press.
- Sommerville, J. A., & Hammond, A. J. (2003). “I did it all by myself”: Exploring preschool children's source-monitoring errors. Poster presented at the *Biennial Meeting of the Society for Research in Child Development*. Tampa, FL, April.
- Tai, Y. F., Scherfler, C., Brooks, D. J., Sawamoto, N., & Castiello, U. (2004). The human premotor cortex is ‘mirror’ only for biological actions. *Current Biology*, *14*, 117–120.
- Vonk, R. (1998). Effects of cooperative and competitive outcome dependency on attention and impressions. *Journal of Experimental Social Psychology*, *34*, 265–288.
- Wing, A. M., Turton, A., & Fraser, C. (1986). Grasp size and accuracy of approach in reaching. *Journal of Motor Behavior*, *18*, 245–260.