Perception directe d'intention sociale depuis les actions motrices

À travers les études 1 et 2, un pattern spécifique de variations cinématiques a été retrouvé pour les actions motrices exécutées avec une intention sociale par comparaison à celles effectuées pour soi-même. Ainsi, lorsqu'une action est réalisée pour autrui, on observe une exagération de ses caractéristiques spatio-temporelles : elle est produite plus lentement et suit des trajectoires davantage courbées. Puisque ces variations cinématiques sont associées à un coût énergétique non-optimal du point de vue de l'individu, nous faisons l'hypothèse que si celles-ci apparaissent de façon consistante, c'est qu'elles sont bénéfiques du point de vue des interactions sociales. Nous postulons ainsi que ces variations ont pour fonction de faciliter la réalisation d'actions impliquant plusieurs personnes. En percevant implicitement des informations relatives à l'intention sociale poursuivie par un individu, il serait possible pour un observateur d'anticiper les actions à venir et ainsi de réaliser une réponse motrice adaptée. Afin de tester cette hypothèse, nous avons conduit une troisième étude sur des participants recrutés par binômes. Les participants venaient par deux au laboratoire et se voyaient aléatoirement attribuer les rôles d'Acteur et de Partenaire (voir description du dispositif expérimental, dans le préambule de cette partie du manuscrit). Cette fois, les signaux sonores déclenchant les différentes actions de la séquence étaient délivrés à l'aide de casques audio, ce qui permettait de transmettre des informations différentes à l'Acteur et au Partenaire. Les sons déclenchant la production de l'*Action préparatoire* chez l'Acteur pouvaient l'informer de la personne qui allait devoir réaliser la prochaine *Action principale* (« Moi », « Lui ») ou ne donner aucune information (« Prêt »). Le Partenaire ne recevait lui que des sons non-

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informatifs (« Prêt »). À nouveau, nous nous attendons à observer un effet de l'intention sociale sur la cinématique des mouvements de l'*Action préparatoire* de l'Acteur. De plus, cette fois, nous nous attendons à ce que les Partenaires soient facilités dans la production des *Actions principales* lorsque l'Acteur a réalisé l'*Action préparatoire* en poursuivant une intention sociale (condition « Lui ») plutôt que lorsque l'Acteur n'a pas d'information (« Prêt »).

Etude 3:

Facilitation effect of observed motor deviants in a cooperative motor task: Evidence for direct perception of social intention in action

Abstract

Spatio-temporal parameters of voluntary motor action may help optimize human social interactions. Yet it is unknown whether individuals performing a cooperative task spontaneously perceive subtly informative social cues emerging through voluntary actions. In the present study, an auditory cue was provided through headphones to an Actor and a Partner who faced each other. Depending on the pitch of the auditory cue, either the Actor or the Partner were required to grasp and move a wooden dowel under time constraints from a central to a lateral position. Before this main action, the Actor performed a preparatory action under no time constraint, consisting in placing the wooden dowel on the central location when receiving either a neutral ("prêt"-ready) or an informative auditory cue relative to who will be asked to perform the main action (the Actor: "moi"-me, or the Partner: "lui"-him). Although the task focused on the main action, analysis of motor performances revealed that Actors performed the preparatory action with longer reaction times and higher trajectories when informed that the Partner would be performing the main action. In this same condition, Partners executed the main actions with shorter reaction times and lower velocities, despite having received no previous informative cues. These results demonstrate that the mere

observation of socially driven motor actions spontaneously influences the low-level kinematics of voluntary motor actions performed by the observer during a cooperative motor task. These findings indicate that social intention can be anticipated from the mere observation of action patterns.

Introduction

Optimal control models of biological movements are used to account for the external and internal variables that constrain voluntary goal-directed actions (Shadmehr & Mussa-Ivaldi, 1994) and contribute to adaptation of human behaviour in the vast diversity of situations normally encountered (Van Beers, Haggard & Wolpert, 2004). Currently, these models have difficulty in accounting for higher levels of action control, in particular with respect to motor and social intentions (e.g., Grafton & Hamilton, 2007). As pointed out by Jacob and Jeannerod (2005), motor intention refers to the intended effects of a goal directed action in the environment, and thus represents one category of internal variables that may substantially influence the planning of voluntary actions. Marteniuk, Mackenzie, Jeannerod, Athenes & Dugas (1987) were the first to show that reach-to-grasp movements towards an object differ depending on the final goal of the grasping movement (e.g. "placing" or "throwing" the object, the former being associated with a longer deceleration phase). The effect of motor intention on spatio-temporal features of motor execution was later confirmed in various grasping tasks (Ansuini, Giosa, Turella, Altoe & Castiello, 2008; Ansuini, Santello, Massaccesi & Castiello, 2006; Naish, Reader, Houston-Price, Bremner & Holmes, 2013; Springer, Hamilton & Cross, 2012), and generalised to pointing (Chary, Méary, Orliaguet, David, Moreaud, & Kandel, 2004), writing (Orliaguet, Kandel & Boë, 1997) and communicative gesturing (Pennel, Coello & Orliaguet, 1999). It was further shown that observing the visuo-spatial variations in motor execution of a purposeful voluntary action permits detection of the motor intention long before the action is completed (Lewkowicz, Delevoye-Turrell, Bailly, Andry, & Gaussier, 2013; Méary, Chary, Palluel & Orliaguet, 2005; Springer, Hamilton & Cross, 2012) and can thus influence interactions during joint actions

when interacting agents share the same motor intention (Bratman, 1992; Newman-Norlund, Noordzij, Meulenbroek, & Bekkering, 2007; Herbort, Koning, van Uem & Meulenbroek, 2012). Social intention is different from motor intention in that it is grounded in interactive contexts in which other actors are needed to satisfy motor goals (Ciaramidaro et al., 2007). Social intention refers to the goal-directed action's intended effects on the co-actor (Jacob & Jeannerod, 2005). Importantly, different social intentions may be associated with the very same motor intention, this being well illustrated by the Dr. Jekyll and Mr. Hyde paradox[5] (Jacob & Jeannerod, 2005). Thus, in contrast to motor intentions, social intentions have been thought to be undetectable by observation of the kinematic parameters of voluntary motor actions (Jacob, 2013; Jeannerod, 2006).

Recent studies have suggested, to the contrary, that social context may influence the performance of voluntary motor actions (Scorolli, Miatton, Wheaton & Borghi, 2014; Quesque, Lewkowicz, Delevoye-Turell & Coello, 2013). For instance, acting in the presence of a confederate influences the kinematic pattern of motor responses, and the extent of this effect depends on the distance between the actor and the confederate (Gianelli, Scorolli, & Borghi, 2013; Quesque et al., 2013). Furthermore, the spatio-temporal features of a grasping

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[5] Put at the forefront of the neuroscientific debate on intentionality by Jacob and Jeannerod (2005), Robert Louis Stevenson's story of "split personality" presents Dr. Jekyll, alias Mr. Hyde, a renowned surgeon who performs appendectomies on his anesthetised patients to heal them during the day, but to murder them during the night. He thus executes the same motor sequence during the day and at night, whereby he grasps his scalpel and applies it to the same bodily part of two different persons. According to Jacob and Jeannerod, Dr. Jekyll's motor intention is the same as Mr. Hyde's, although Dr. Jekyll's social intention (improving patient's health) clearly differs from Mr. Hyde's social intention (enjoying victim's agony). Social intention was thus thought to be hardly identifiable from movement characteristics.

movement differ when a confederate serves as the target for the motor action (Becchio, Sartori, Bulgheroni & Castiello, 2008b; Ferri, Campione, Dalla Volta, Gianelli & Gentilucci, 2011) or when the goal of the motor action is to manipulate the object with the social intention of communicating information to a confederate (Sartori, Becchio, Bara & Castiello, 2009). These effects on movement kinematics have been interpreted as providing implicit but potentially informative signals that can be used by social agents when communication or interaction processes are engaged (Sartori et al., 2009). However, as noted by Obhi (2012), when probing the observers' capacity to identify the effects of social context on action parameters, the tasks used were often explicit and categorical (e.g., forced-choice paradigm distinguishing social and non-social conditions, Sartori, Becchio & Castiello, 2011; Manera, Becchio, Cavallo, Sartori & Castiello, 2011). Consequently, even if the effect of social context on the kinematics of voluntary motor actions is suggested by a large amount of data, there is yet no specific evidence supporting the idea that observers are sensitive to the effect of social intention on the observed motor action (see Quesque & Coello, 2015, for a discussion). Furthermore, no study has reported whether motor variations can be observed and used, however subtly, in a cooperative motor task.

To investigate these issues we recently developed an original sequential motor task that allows direct assessment of whether humans show specific sensitivity to the effect of social intention on spatio-temporal characteristics of voluntary motor actions (Quesque et al., 2013; Quesque & Coello, 2014). The sequential motor task comprised a Preparatory and a Main action performed successively from the same starting location. The Preparatory action was always performed by the Actor and consisted in moving a wooden dowel along the mid-body axis from a nearby to a central location, without time constraints, and in full view of the Partner. The Main action was performed by either the Actor or the Partner (different

sessions). It was time constrained (> 80% of the possible maximum speed) and consisted in moving the wooden dowel from the central to a lateral location. Although the Preparatory action was always performed by the Actor, Quesque et al. (2013, 2014) found that it was influenced by whether the up-coming Main action was performed by the Actor or the Partner. More specifically, reaction times increased and the hand path revealed a higher elevation when the wooden dowel was placed for the Partner. This study thus demonstrated that the social intention associated with the Preparatory action influences its execution, although this was never explicitly perceived by the participants.

The aim of the present study was to assess whether Partners show specific sensitivity to the effect of social intention on voluntary motor actions and whether this influences the planning of their own motor actions. We used an experimental paradigm similar to the one used by Quesque et al. (2013, 2014) in which either an Actor or a Partner performed the Main action depending on the pitch of an auditory cue. However, the present study had two novel features. The Main action was executed randomly by either the Actor or the Partner as a function of the pitch of an auditory cue, and another cue was provided to the Actor (but not to the Partner) prior to performing the Preparatory action. This private cue told the Actor who would be performing the up-coming Main action. Assuming that the Partner is sensitive to motor deviants that are related to social intention, in particular those revealed during the Preparatory action, we predicted that the Partner's motor patterns during the Main action are implicitly influenced by the motor patterns revealed in the Actor's Preparatory action depending on the Actor's social intention.

Material and methods

Participants

Forty healthy adults were recruited as working dyads. Participants were all right-handed (as determined by the Edinburgh Handedness Inventory, Oldfield, 1971) and were between 20 and 30 years of age (mean age = 22.2 years, SD =2.2 years). They had no prior knowledge about the scientific aim of the study and provided written informed consent before participating. The protocol followed the ethical standards defined by the local IRB and conformed to the principles of the Declaration of Helsinki (World Medical Association, 2013).

Apparatus and procedure

The participants' task was to grasp and move a wooden dowel (diameter 2 cm, height 4 cm) on a table (120 cm x 80 cm) on which black markings (2 cm x 2 cm) indicated three specific locations that will be referred hereafter as the initial, central and final positions. In addition, the starting positions of the participants' right hand were indicated by black markings (10 cm x 10 cm) placed at the edges of the table. Participants were seated on either side of the table, facing each other and were respectively called the "Actor" and the "Partner" (roles were randomly assigned to each pair of participants). The central position was situated at the centre of the table equidistant from the Actor and the Partner. The initial position was midway between the central position and the Actor's starting position. The task was to move the wooden dowel from the initial to the central location, then from the central to the final location and finally from the final to the initial location in a sequence of three successive manual actions: a Preparatory action, a Main action and a Repositioning action (see Figure 1). The Preparatory action was always performed by the Actor and consisted of moving the

wooden dowel, under no time constraint, from the initial to the central position (15 cm). The Main action (performed either by the Actor or the Partner – see below) consisted of moving the wooden dowel from the central to the final position (15 cm) as fast as possible. The Repositioning action was always performed by the Actor, and consisted in moving the wooden dowel, under no time constraint, from the final to the initial position, thus readying the setup for the next trial. Thus, time constraints were placed only on the Main action, perceived by the participants as the important component of the sequential task in which the speed of the participants' wrist was required to be greater than 80% of maximal speed, the latter being registered in a pre-experiment session (see below). The Actor and the Partner set their hand back to the starting position after each movement in the sequence.
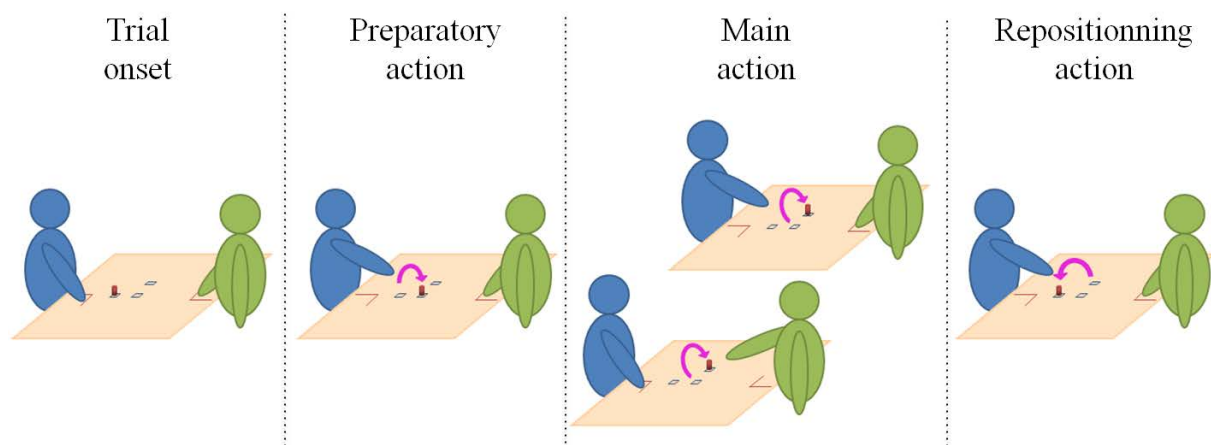
Figure 1. The actions' sequence always started with the wooden dowel placed on the initial location target and with the Actor (in blue) and the Partner (in green) pinching their index finger and thumb together on their respective starting location. The Preparatory action consisted for the Actor in displacing the object from the initial to the central location. The Main action consisted for either the Actor or the Partner in displacing the dowel from the central to the final location. Finally, the Repositioning action was always performed by the Actor and consisted in displacing the wooden dowel from the final to the initial location, making the setup ready for the next trial.

Each movement in the sequences was triggered by an auditory cue, which was individually delivered through headphones to both the Actor and the Partner. Auditory cues used to trigger the Preparatory action performed by the Actor could be either a neutral word ("prêt"-ready) or an informative word (the Actor: "moi"-me, or the Partner: "lui"-him), indicating to the Actor (only) which of the two would perform the up-coming Main action. The Partner always received a neutral word and was not aware of the fact that the Actor received either a neutral or an informative word. The auditory cue for the Main action was either a low- or a high-pitched sound (50:50 randomly), indicating to the both participants whether the Main action was to be performed by the Actor (high-pitched) or by the Partner (low-pitched). Low- and high-pitched auditory cues (50 trials each) were delivered while the Actor knew in advance (Preparatory action cue) which person was to perform the Main action (50% of the trials) or not (50% of the trials). Hence, the Partner could never anticipate who would be doing the Main action. The Repositioning action cue was a constant pitch sound, either a clinking of coins or a buzz, which signified respectively success or failure regarding the speed and accuracy of the motor performance of the Main action. In order to prevent anticipatory strategies by the participants in particular during the Main action, the inter-trial interval varied randomly between 3 and 3.5 s; the interval between the Preparatory action and the Main action auditory cues varied randomly between 3.5 and 4 s and the interval between the Main action and the Repositioning action auditory cues was fixed to 2 s (see Figure 2).
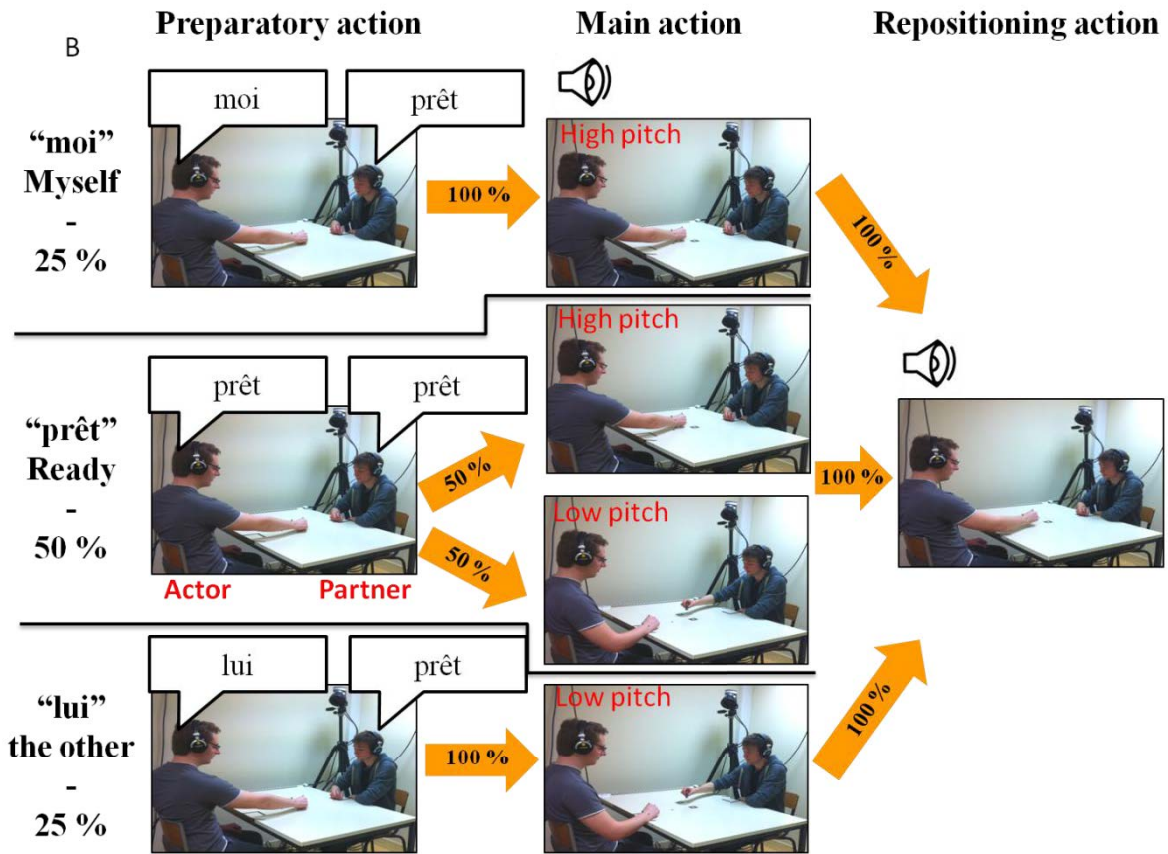
Figure 2. Representation of the experimental design and the different experimental conditions.

Before the start of the session, all participants underwent three practice blocks of 15 trials each. The first practice block was performed to obtain an estimate of the maximum speed at which the participants could grasp the wooden dowel from the central position and place it accurately in the final position (Main action). We used an adjustment procedure similar to the one used in Quesque et al. (2013). The second practice block was done to familiarise the participants with the different auditory cues and the appropriate motor responses. In this practice block, participants did not wear the headphones and they heard the auditory cues through speakers. Only the "prêt"-ready auditory cue was used to trigger the Preparatory action performed by the Actor; the low- and high-pitched cues were used to trigger the Main action performed by either the Actor or the Partner. The clinking of coins and buzz sounds were used to trigger the Repositioning action performed by the Actor. At the end

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of the practice blocks and before starting the experiment proper, participants took their headphones off and were individually given written instructions while nothing was said about the fact that that the instructions were different for Actor and Partner. In particular, the Actor was informed that the cue used to trigger the Preparatory action would be either a neutral word ("prêt"-ready) as in the practice block, or an informative word indicating who would perform the Main action (the Actor: "moi"-me, or the Partner: "lui"-him). The Partner was instructed that the cue used to trigger the Preparatory action was always a neutral word ("prêt"-ready) as in the practice block. Both the Actor and the Partner were also informed that the auditory cues used to trigger the Main action and the Repositioning action would be those heard during the practice block.

From that moment on, participants were not allowed to communicate and they were asked to keep their gaze set on the table, i.e., gaze set on the wooden dowel. The experimenter was present during the whole session so as to ensure that participants followed the instructions and did not communicate. An experimental block of 100 trials was then performed; a short rest was given every 25 trials. The Actor performed 100 Preparatory actions, 50 Main actions (25 following the auditory cue "moi"-me and "prêt"-ready respectively in the Preparatory action) and 100 Repositioning actions. The Partners performed 50 Main actions only (25 following a Preparatory action performed by the Actor with the auditory cue "lui"-him; 25 following a Preparatory action performed by the Actor with the auditory cue "prêt"-ready). During the Preparatory action, the Partners always received the neutral "prêt"-ready auditory cue.

Post-experiment debriefing was done to assess whether the Actors were aware of the expected effects of auditory cuing on motor performances, and whether the Partners were aware that

different instructions had been given to the participants. This was the case in none of the participants. In all the session lasted approximately 45 minutes.

Data recording and analysis

The participants' motor performances were recorded using Qualisys 4 Oqus infrared cameras (Qualisys AB, Guthenburg, Sweden). Infrared reflective markers were placed on the forefinger (base and tip), the thumb (tip) and the wrist (scaphoid) of the participants' right hand. One additional marker was placed on the wooden dowel. Cameras were calibrated before each session, allowing the system to reach a standard deviation accuracy of maximum 0.2 mm, at a sampling rate of 200 Hz. Each action in the motor sequence was characterised by a grasping phase and a transport phase. The focus was placed on movement parameters that are known to be affected by social intention, namely reaction time, movement time, peak wrist velocity, and height of the trajectory in the grasping and transport phases (Becchio et al., 2008; Quesque et al., 2013, 2014). Reaction times, movement times and trajectory elevations were computed from the 3D coordinates of the reflective marker placed on the wrist using RTMocap toolbox for Matlab (Lewkowicz & Delevoye-Turrell, 2015). Temporal and kinematic parameters of the (x,y,z) coordinates of the wrist marker were computed from tangential velocity profiles after filtering the data using a second-order Butterworth dual pass filter (cutoff frequency: 15 Hz). Movement onset was defined as when the first velocity value reached 20 mm.s^{-1}. Movement end was defined as the time the velocity profile reached the minimum value following peak velocity in the transport phase. Reaction time corresponded to the time separating the Preparatory action auditory cue from movement onset. Movement time corresponded to the time separating movement onset from movement end. Peak wrist velocity corresponded to the maximum velocity reached by the wrist during the grasping and transport

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phase, respectively. The maximum height of trajectory was defined as the maximum z coordinate of the wrist measured in the grasping and transport phases.

A one-way repeated-measures ANOVA with three levels corresponding to the type of prior information given to the Actor about the Main action (neutral information-"prêt", Actor Main action-"moi", Partner Main action-"lui") was computed on the following variables: mean reaction times, mean movement times, peak wrist velocities, and maximum heights of the grasping and transport phases of hand trajectories. Post-hoc comparisons were performed using Tukey's HSD test (α=.05 for all comparisons). Effect sizes were indexed using partial Eta-squared (η^2_p).

Results

Trials were excluded from the analysis if a participant responded erroneously, if the marker was not registered correctly during the entire movement, or if reaction time was shorter than 200 ms or longer than 2.5 standard deviations from the median (Leys, Ley, Klein, Bernard, & Licata, 2013). In the present study, 7.7% and 9.2% of the Main and Preparatory actions were excluded for these specific reasons, respectively. These exclusions were distributed approximately equally across the conditions.

Preparatory action performed by the Actors

Concerning the Preparatory action, we found for reaction time a significant effect of prior information provided to the Actors (F(2,38)=78.96, p<.001, η^2_p=.81). Mean reaction time was longer when Actors acted on the wooden dowel knowing that the Partners would perform the Main action (553 ms) compared to when they knew that the Main action was to be performed by themselves (473 ms, p<.001) or when they received neutral information (487 ms, p<.001). The differences found between the two latter conditions did not reach

significance (p=.12). We also found that prior information had a significant effect on wrist elevation during the transport phase (F(2,38)=5.64, p<.01, η^2_p=.23), namely movement trajectory arched higher when the Actors knew that the Partners would be performing the Main action (62.6 mm) compared to when the Actors knew that they themselves would be performing it (61.4 mm, p=.012) or when they received neutral information (61.5 mm, p=.022). Wrist elevation did not differ significantly between the two latter conditions (p=.97). No other significant effects of prior information on movement times or kinematic parameters, either on the grasping or on the transport phases, were revealed in the Preparatory action (see Table 1 and Figure 3).

### Main action performed by the Actors

When the Actors knew in advance that they were to perform the Main action, mean reaction time of the Main action (355 ms) was shorter than when they received neutral information (441 ms, F(1,19)=146.07, p<.001, η^2_p =.88). Moreover, the grasping phase was slower (486 ms vs 468 ms, F(1,19)=11.94, p=.003, η^2_p =.39) and was performed with a lower peak velocity (1189 vs 1227 mm.s^{-1}, F(1,19)=15.34, p<.001, η^2_p =.45), and lower elevation (65.6 vs 68.1 mm, F(1,19)=146.07, p<.001, η^2_p =.88). No effects were observed in the parameters of the transport phase (see Table 1 and Figure 3).

Main action performed by the Partners

Although they themselves always received neutral auditory cues during the Preparatory action, the Partners' motor performances during the Main action were characterised by shorter reaction times (457 vs 467 ms, F(1,19)=8.13, p=.010, η^2_p =.30), and longer grasping phases (443 vs 439 ms, F(1,19)=4.34, p=.049, η^2_p =.19) when the Actors knew in advance that the Partners would be performing the Main action compared to the

condition in which the Actors received neutral information. The Partners' grasping phase also showed lower peak velocity (1293 vs 1309 mm.s^{-1}, $F(1,19)=6.17$, $p=.022$, $\eta^2_p =.25$), as did the Transport phases (692 vs 701 mm.s^{-1}, $F(1,19)=7.98$, $p=.011$, $\eta^2_p =.30$, see Table 1 and Figure 3).
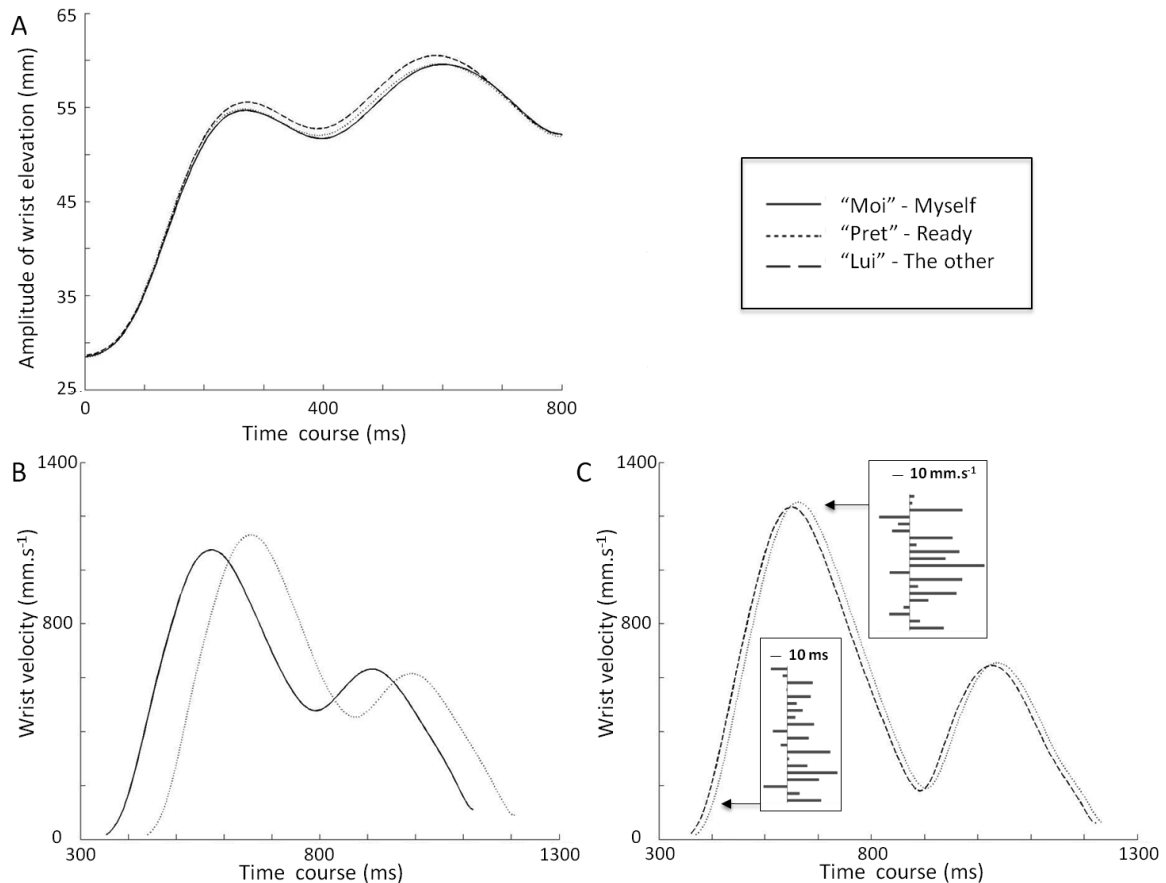
Figure 3. A) Mean trajectories of the Preparatory action in the sagittal plane and B) mean kinematic patterns of the Main action in the different experimental conditions for the Actors. C) Mean kinematic patterns of the Main action in the different experimental conditions for the Partners. Individual variations of performances for reaction time (ms) and wrist peak velocity (mm.s-1) in the conditions tested are also reported for the Partners.

Table 1. Mean reaction time (ms), maximum wrist velocity (mm.s-1), maximum wrist elevation (mm), and movement time (ms) of the grasping and transport phases for the Actors' Preparatory action, Actors' Main action and Partners' Main action. Standard deviations are shown in brackets. * p<.05, ** p<.01, † p<.001 for comparison with irrelevant prior information condition (PRÊT-Ready).

	Auditory cue for the Preparatory action		
Actor's Preparatory action	**MOI-Self**	**PRÊT-Ready**	**LUI-Other**
Reaction time (ms)	473 (71)	487 (76)	553 (87) †
Grasping phase			
Maximum wrist velocity (mm/s)	665 (79)	670 (81)	672 (81)
Maximum wrist elevation (mm)	56.1 (8.5)	56.5 (8.5)	56.6 (7.5)
Movement time (ms)	411 (50)	416 (47)	408 (44)
Transport phase			
Maximum wrist velocity (mm/s)	586 (73)	585 (75)	586 (71)
Maximum wrist elevation (mm)	61.4 (8.1)	61.5 (7.9)	62.6 (7.7)**
Movement time (ms)	402 (80)	412 (84)	403 (74)
Actor's Main action	**MOI-Self**	**PRÊT-Ready**	**LUI-Other**
Reaction time (ms)	355 (38) †	441 (37)	-
Grasping phase			
Maximum wrist velocity (mm/s)	1189 (151) †	1227 (143)	-
Maximum wrist elevation (mm)	65.6 (9.2) †	68.1 (9.1)	-
Movement time (ms)	486 (72) **	468 (71)	-
Transport phase			
Maximum wrist velocity (mm/s)	668 (125)	658 (100)	-
Maximum wrist elevation (mm)	65.2(8.2)	65.7 (8.1)	-
Movement time (ms)	349 (71)	344 (54)	-
Partner's Main action	**MOI-Self**	**PRÊT-Ready**	**LUI-Other**
Reaction time (ms)	-	467 (37)	457 (37) *
Grasping phase			
Maximum wrist velocity (mm/s)	-	1309 (152)	1293 (140) *
Maximum wrist elevation (mm)	-	70.5 (8.9)	70.1 (8.7)
Movement time (ms)	-	439 (49)	443 (45) *
Transport phase			
Maximum wrist velocity (mm/s)	-	701 (89)	692 (86) *
Maximum wrist elevation (mm)	-	79.5 (10.3)	79.8 (9.8)
Movement time (ms)	-	338 (43)	339 (44)

In order to confirm that the effects observed in the Partners' motor performances were related to the variations in the Actors' Preparatory actions, we analysed the spatial and temporal variations of the Partners' motor responses as a function of the characteristics of the Actors' performances in the condition for which the Actors knew in advance that the Partners would be performing the Main action. For each dyad, we divided the Actors' performances into two sets including (a) the trials in which transport phase reaction time and wrist elevation both fell below their respective median values (benchmarks) seen in the preparatory action (26% of the trials) or (b) the trials in which transport phase reaction time and wrist elevation both rose above their respective median values (benchmarks) seen in the preparatory action (27% of the trials). Comparing the performances of the Partners across those two sets of trials, we found that they responded with shorter reaction times ($F(1,19)=3.085$, $p=.047$, $\eta^2_p=.14$, with respectively 457 ms and 466 ms) and had slower grasping phases ($F(1,19)=3.174$, $p=.045$, $\eta^2_p=.14$, with respectively 445 ms and 438 ms) that were characterized by lower peak velocities ($F(1,19)=4.45$, $p=.02$, $\eta^2_p=.19$, with respectively 1290 mm.s^{-1} and 1311 mm.s^{-1}) when the Actors produced the Preparatory action with longer reaction times and higher wrist elevations with respect to their benchmark median values. Overall, these results strongly suggest that it was the kinematic variations associated with the Actors' social intention that influenced the motor planning of the Partners' voluntary action.

Discussion

The aim of the present study was to examine whether motor deviants emerging from social intention can be directly perceived through the observation of the kinematic patterns of motor actions performed by a partner. To assess this question avoiding explicit judgments (Sartori, Becchio & Castiello, 2011; Manera, Becchio, Cavallo, Sartori & Castiello, 2011), we used an experimental paradigm in which either an Actor or a Partner performed a Main action after the Actor had previously performed a Preparatory action. The novel feature of the present study was that the Preparatory action was initiated from an auditory cue informing the Actors (but not the Partners) about who would be asked to perform the up-coming Main action. Previous studies have shown that performing a Preparatory action while knowing that the Main action will be performed by the Partner modifies the kinematic pattern of the motor performance (Quesque et al., 2013, Quesque & Coello, 2014, but using blocked sessions). Furthermore, when the Actors knew that they would need to perform the Main action, the latter was performed differently. In this context, assuming that individuals are sensitive to the social intentions emerging through motor actions, we hypothesized that the Main actions performed by the Partners would be influenced by the Preparatory actions performed by the Actors when the latter were modulated by social intention.

First, concerning the influence of the social context on motor performances, our data confirm previous findings. Concerning in particular the Preparatory action: Actors took more time to initiate their actions (Quesque et al., 2013; Quesque & Coello, 2014) and produced higher hand trajectories (Becchio et al., 2008b; Quesque et al., 2013; Quesque & Coello, 2014) when they moved the wooden dowel for the Partners rather than for themselves. Such an exaggeration of movement characteristics has been previously interpreted as an implicit

strategy to catch the Partner's attention, the movements being performed with a greater amplitudes in relation to the Partner's eye level (Quesque & Coello, 2014). Indeed, numerous studies have pointed out the predominant role of gaze in human's social interactions (Becchio, Bertone & Castiello, 2008; Kleinke, 1986; Langton, Watt, & Bruce, 2000). It then makes sense to consider eye-level as a crucial element of non-verbal communication and thus influencing the implementation of goal-directed action performed in a social interaction context (Quesque & Coello, 2014). Moreover, when the Actors knew in advance that they would need to perform the Main action, it was performed with shorter reaction times and longer movement durations associated with lower velocity peaks (Quesque et al., 2013). Overall, these results replicate previous findings (Quesque et al., 2013; Quesque & Coello, 2014), but using a randomized design. The striking finding of the present study was that a similar pattern of results was observed when the Partners performed the Main action. Concretely, Partners' responses showed shorter reaction times, and movements were slower and performed with lower peak velocities when the Actors initiated the Preparatory action knowing that the Partners would be the one to perform the Main action. This was in contrast to the patterns of results obtained when the Actors received no social cueing (neutral information condition). Thus, Partners responded as if they had received explicit prior information about who would be called on to perform the Main action. These findings suggest that the social cues available within the Actors' Preparatory actions were perceived by the Partners in a totally implicit fashion. This was confirmed by the post-session interviews, which revealed that none of the participants were aware of variations occurring in the Actors or Partners' responses. Overall, these results support the idea that the perception of social intention from action kinematics relies on low-level mechanisms and does not necessarily involve conscious inferences (Gallagher, 2008). Thus, contrary to what was claimed until

recently (e.g., Jacob & Jeannerod, 2005; Jacob, 2013), the present study suggests that kinematics variations associated with social intention can be spontaneously perceived in others' voluntary motor actions when performed in a truly interactive social context. It furthermore modifies the planning of self-initiated actions.

The effect observed in the motor kinematics due to the social aspect of the task cannot be attributed to direct communication between participants because both the Actors and the Partners were consistently staring at the target-object on the table and remained silent throughout the experiment. This effect was also not associated with a change in the position of the wooden dowel on the central position at the end of the Preparatory action, as the location of the wooden dowel was carefully controlled and did not differ when it was placed for the Actors or the Partners, respectively. Similarly, the social effects on the motor performances were not related to changes in how the Actors reached the starting location after having transported the wooden dowel during the Preparatory action, since we found no variations in the kinematic patterns for this movement phase across conditions. Furthermore, it is also important to note that the effects of the Actors' Preparatory action on the Partners' performances cannot be interpreted in terms of spontaneous mimicry or direct matching of participants' performances (Becchio, Sartori, Bulgheroni & Castiello, 2008a; Liepelt, von Cramon & Brass, 2008; Chartrand & Bargh, 1999). Indeed, the effect of prior information on the Partners' Main action was opposite to the effect of prior information on the Actors' Preparatory action. Namely, when the Actors took a longer time to initiate their actions, the Partners had relatively short reaction times. Thus, and congruently with the results of the analyses performed on the Partners' kinematic patterns as a function of the characteristics of the Actors' movements, we suggest that the relevant cues for perceiving social intention from the Actors' motor actions were available within the spatio-temporal characteristics of

Preparatory actions. In agreement with this, a recent study performed by Lewkowicz, Quesque, Coello & Delevoye-Turrell (2015) showed that individuals are able to classify video clips presenting reach-to-grasp actions with a personal or social intention, although only the displacement of the hand is visible. Moreover, prediction reached chance-level when the video clips were normalized to control for reaction or movement time of the grasping action, suggesting that the ability to (implicitly) use motor deviants represents the key aspect of intuitive social interaction.

In conclusion, using an original sequential task, the present study shows that the social context can influence the way a reach-to-grasp action is performed with no clear meaning about its social consequences (Preparatory action). Observers can take advantage of these motor deviants to modulate their own action performances. Hence, we suggest that the detection of subtle kinematic variations of object-oriented movements performed in a social context can prime the perceiver to prepare for social interaction and anticipate appropriate motor responses, even in the absence of explicit access to the meaning of the kinematic variations. Future work is now needed to better understand how social context and motor expertise modulate the perception of motor deviants associated with social intention. An important question concerns for example the relationship between individual motor repertoires and the perception of motor deviants related to social intention. Another key question targets the effect of social constraints in competitive vs. cooperative situations. It would also be useful to evaluate whether the influence of a social context arises in non-predefined multi-agent communicative situations. All these issues open new avenues of research within the embodied approach of social cognition.