

The effect of social context on the use of visual information

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Received: 16 April 2011 / Accepted: 1 August 2011 / Published online: 24 August 2011
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Abstract Social context modulates action kinematics. Less is known about whether social context also affects the use of task relevant visual information. We tested this hypothesis by examining whether the instruction to play table tennis competitively or cooperatively affected the kind of visual cues necessary for successful table tennis performance. In two experiments, participants played table tennis in a dark room with only the ball, net, and table visible. Visual information about both players' actions was manipulated by means of self-glowing markers. We recorded the number of successful passes for each player individually. The results showed that participants' performance increased when their own body was rendered visible in both the cooperative and the competitive condition. However, social context modulated the importance of different sources of visual information about the other player. In the cooperative condition, seeing the other player's racket had the largest effects on performance increase, whereas in the competitive condition, seeing the other player's body resulted in the largest performance increase. These results suggest that social context selectively

modulates the use of visual information about others' actions in social interactions.

Keywords Social context · Competition · Cooperation · Visual information · Table tennis · Performance

Introduction

Humans are social beings, and their interaction often requires the concerted coordination of actions in time and space to accomplish their goals (Sebanz et al. 2006), for example, when two people play table tennis. The correspondence between an individual's goals and the interaction partner's goals defines the social context (Manstead and Hewstone 1996). If the goals of the interaction partners are in positive correspondence, for example, when the goals are complementary or the same, the interaction partners cooperate. In contrast if the interaction partners' goals are in negative correspondence, the attainment of one person's goal results in the failure to achieve the other person's goal. In this case, the interaction partners compete. The investigation into the effects of social context (i.e., of competition and cooperation) on an individual's behavior has a long-standing history in social psychology (e.g., Triplett 1898). More recently, researchers have started to investigate the cognitive and neural processes involved in cooperative and competitive behavior during human interaction.

This research has shown that cooperation and competition are associated with different cortical activity as measured by fMRI (Decety et al. 2004; de Bruijn et al. 2009) and differences in behavior (Georgiou et al. 2007; Becchio et al. 2008; Ruys and Aarts 2010). Specifically, some of the latter studies suggest that action coordination in

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cooperative and competitive settings involves distinct motor planning mechanisms.

Georgiou et al. (2007) found that kinematic trajectories of the very same action are modulated by social context. Specifically, they analyzed the kinematics of participants' reach-to-grasp movements toward a wooden block with different action goals. In the critical conditions, either participants built a tower of blocks together with a co-actor in a cooperative fashion or they competed with a co-actor to place a block in the middle of the table first in order to build a tower. The kinematic patterns of the reach-to-grasp movement differed significantly from each other depending on whether the action goal was cooperative or competitive. Specifically, kinematic patterns of the two interaction partners were significantly correlated in the cooperative condition but not in the competitive condition. The authors suggested that the social context influences the social intentions which in turn affects motor planning and consequently results in different kinematic patterns during competitive and cooperative behavior.

Indeed, in a more recent study, Becchio et al. (2008) found evidence that intentions alter kinematic patterns. In the critical conditions, one participant was seated opposite to a confederate of the experimenter (a trained actor) at a table with two blocks in between them. The participant and the actor had to reach and grasp one block (reach-to-grasp phase), and then, they stacked the objects on top of each other to build a tower (tower-building-phase). In the competitive condition, participant and actor competed for placing the bottom block of the tower. In the cooperative condition, the participant and actor were assigned roles as to who should build the bottom and the top part of the tower. To see whether intentions modulate the kinematic patterns of the participant, the actor showed incongruent behavior within a given social context on some trials (incongruent trials) prior to the actor's execution of an action. Specifically, the actor showed a competitive attitude (in terms of her facial expression and body posture) in the cooperative condition and a cooperative attitude in the competitive condition. This change of attitude on these incongruent trials was confined to the reach-to-grasp phase of the actor's movement. Interestingly, participants' kinematic patterns in the reach-to-grasp phase differed on incongruent and congruent trials, suggesting that showing a different attitude and intention before the actual action influences the kinematic patterns (Becchio et al. 2008). These results are in line with the idea that social context changes the intentions of the interaction partners which in turn affects motor planning and leads to different kinematic patterns.

Do changes of the social context only affect the way humans carry out motor actions, or do they also affect the way they process visual information from the

environment? If social context was to change the visual information that is important for a given task, this would provide further evidence for the idea that interacting with another person and acting alone rely on different psychological mechanisms (e.g., Knoblich and Sebanz 2008; Becchio et al. 2010). Furthermore, identifying which visual information is most important in a given social context improves our understanding of the nature of the perceptual and cognitive processes that are at play in a particular social context.

How might social context affect the processing of task relevant visual information? One way in which social context might alter the processing of task relevant visual information is by changing the intentions of the interaction partners, which results in changes to their motor plans. If motor planning and visual information were closely linked, one would expect that social context might also affect the way humans look at the environment in different social contexts. In line with this idea, studies on eye gaze behavior during motor tasks suggest a close link between the eye gaze behavior and the particular task. The investigation into gaze behavior during object interaction tasks reveals that participants look at *task-specific* landmarks that are critical for the action control of the given task before the action is completed (Johansson et al. 2001; Lee et al. 1983). For example, when participants were instructed to stack objects on top of each other, participants focused their gaze on the objects before they actually stacked one object on top of the other (Sailer et al. 2005). Johansson et al. (2001) suggested that the visual information at the gaze location is used for the motor planning.

This idea is supported by other research on online control of actions in object interaction tasks. These studies suggest that visual information is being used for the online control of action (McLeod and Dienes 1993; Mcbeath et al. 1995; Cressman et al. 2010; Sarlegna and Blouin 2010; Grierson et al. 2009; Bootsma and Vanwieringen 1990). For example, baseball players adjust their catching behavior in an online fashion to disturbances of the baseball's flying trajectory (Fink et al. 2009). These studies suggest a close link between visual information and motor planning. Taken together, the link between social context and motor planning and the link between visual information and motor planning imply that social context also changes the way humans look at the environment.

We tested the hypothesis that social context modulates the use of visual information during social interactions by means of a table tennis task. Pairs of participants played a table tennis game in either a cooperative (Experiment 1) or competitive (Experiment 2) fashion. During the experiment, we manipulated (for each player separately) the visibility of visual information about the players' rackets and body movements. We measured table tennis

performance by means of the number of successful passes for each player separately. We reasoned that if a particular source of visual information is important for playing table tennis, rendering this source of visual information visible should positively affect the players' table tennis performance. We used this logic to assess the importance of different sources of visual information in different social contexts. If a particular source of visual information improves table tennis playing performance in one social setting (e.g., cooperation) but not in the other one (e.g., competition), it would indicate that the importance of this source of visual information was modulated by social context.

To this end, we manipulated four sources of visual information in two different social contexts. We examined the effect of (1) the visibility of a player's own body, (2) the visibility of the other player's body, (3) the visibility of a player's own racket, and (4) the visibility of the other player's racket on the percentage of successful passes in cooperative (Experiment 1) and competitive (Experiment 2) table tennis play.

Experiment 1

The purpose of Experiment 1 was to investigate the importance of different sources of visual information during cooperative table tennis play. We manipulated the visibility of the racket and the body for each player separately. We decided to use point-light-like stimuli for manipulating visual body information to ensure that the stimuli employed in the experiment highlight the dynamic aspect of an action and thereby the interactive component of the task. One class of stimuli that is well suited for this purpose are point lights as they are deprived of figural cues and rich of motion cues (Johansson 1973).

Previous research showed that humans can infer action relevant information by observing the other person's racket and body. For example, the availability of visual information about the other player's racket improves the prediction of ball trajectories in tennis (Huys et al. 2009; Mann et al. 2010) and squash (Abernethy 1990). Moreover, participants fixate on the other player's racket when they predict a stroke (Ward et al. 2002). The improved prediction performance of the ball trajectory when seeing the other player's racket should lead to an increase in successful table tennis strokes in the current experiment.

Similarly, previous research suggests that participants can infer action intentions from observing the interaction partner's body. For example, humans are able to identify the intentions underlying observed body movements from

point light stimuli (Runeson and Frykholm 1983; Barrett et al. 2005). Point lights are devoid of figural cues but preserve the essential movement kinematics of an action (Johansson 1973). In previous research, point-light stimuli were exclusively presented on video displays in order to demonstrate isolated observer's ability to detect the kind of actions performed (Dittrich 1993; Vanrie and Verfaillie 2004) and also the actor's expectations (Runeson and Frykholm 1983) and intentions (Grezes et al. 2004). Knowing the intentions of the other player might facilitate performance because observers can predict what the other person is going to do next. For example, goal keepers can better predict the fate of a penalty kick when observing the body of the penalty kicker prior to ball contact (Savelsbergh et al. 2002). Also, basketball players can better predict the fate of a basketball shot when observing the body of the shooter (Aglioti et al. 2008; Sebanz and Shiffrar 2009) before the ball is released from the hand. These results suggest that visual information about the other player's body enhances action prediction, which in turn should also improve the number of successful passes in a joint table tennis task.

However, most of these experiments were conducted under conditions that more closely resemble competitive than cooperative settings. One important difference between cooperative and competitive conditions is that the goals of the interaction partners are in line and therefore known to each other (Van Avermaet 1996). Hence, predicting goals should not be necessary in cooperative play. We therefore hypothesized that the visibility of the other player's racket and possibly the visibility of the other player's body should not affect cooperative table tennis performance.

Visual information about one's own arm is important for the online control of arm movements. For example, the visibility of one's own arm leads to improved reaching accuracy (Bard et al. 1985; Spijkers and Spellerberg 1995; Proteau et al. 2000) and faster adjustments of incorrect arm movements (Reichenbach et al. 2009). In light of this, we hypothesized that players' performance will benefit from the visibility of their own body due to a better online control of arm movements. We are not aware of any research examining the effect of the visibility of one's own racket on playing performance in racket sports. Hence, the results of Experiment 1 will also help to shed light onto the effects of seeing one's own racket on playing performance.

Methods

Participants

Twenty-eight right-handed participants were tested (mean age: 29.61; SD: 5.6). Data of one pair were lost due to a

technical error. The data analysis was carried out on the data of the remaining 13 pairs (three male pairs, two female pairs, and eight mixed pairs). All participants had normal or corrected-to-normal vision. Participants were recruited from the Max Planck Institute Subject Database and were naive with respect to the purpose of the study. This research was performed in accordance with the ethical standards specified by the 1964 Declaration of Helsinki. All participants gave their informed consent prior to the experiment and received 8 Euros per hour for their participation.

Stimulus and apparatus

Participants played table tennis in a windowless darkened room of 4 × 5 m. A standard table tennis table (length: 2.74 m, width: 1.53 m; height: 0.76 m) was located in the center of the room. The four corners of the table were painted with fluorescent paint. The top edge of the table tennis net was also painted with fluorescent paint. Two sets of two table tennis rackets were used. One set had the rim painted with fluorescent paint, and the other consisted of normal rackets without the paint. Furthermore, fluorescent body markers (compressed cotton balls with a diameter of 3 cm) were attached with Velcro to a headband and black sweaters that participants wore on top of their clothes. The markers were placed at the wrist, elbow, shoulder, upper sternum, and forehead on both the left and the right sides of the body. Fluorescent tape (30 × 3 cm) was attached at 1.5 m height to each of the four walls to avoid participants colliding with the walls when playing in the dark. The stimuli as seen from a participant's view in the different conditions are shown in Fig. 1.

A microphone was mounted under the middle of the table to record when the ball hit the table and to record participants' verbal responses. The sound was recorded by means of custom written software on a computer. This

computer also served for the manual recording of the hits and errors by the experimenter.

The table tennis ball was also painted with fluorescent paint, which slightly changed its physical response properties (e.g., bouncing). However, these changes did not affect the play as indicated by participants' reports. The same ball was used in all experimental conditions.

In order to validate the experimental environment, a pilot study was performed in which 14 pairs of participants played cooperative table tennis in two different conditions. In the "light on" condition, participants played cooperative table tennis under normal light condition. In the "dark room" condition, participants played cooperative table tennis with the self-glowing markers attached to both participants and the rackets of both participants visible. Performance was measured as the percentage of successful passes out of 60 passes. The average performance score in the "light on" condition was slightly higher (mean performance: 93.83% of successful passes; SD: 4.82) than in the "dark room" condition (mean performance: 92.62% of successful passes; SD: 5.35). However, a paired *t* test, $t(14) = 1.32$, $P = 0.210$, did not reveal a significant difference between the performance scores in both conditions. In sum, this suggests that the body markers and the rackets provide all necessary information in order to reach a normal performance level (as in the lights on condition).

Design

The effect of visibility was investigated in eight experimental conditions. In all eight conditions, the ball was always visible. In the 'Racket A' and 'Racket B', condition player A or player B was playing with a fluorescent racket, respectively. In the 'Racket A + B' condition, the rackets of both participants were visible. In the 'No Racket' condition, nothing else except for the ball was visible. In the 'Body A' and 'Body B' condition, player A or player B

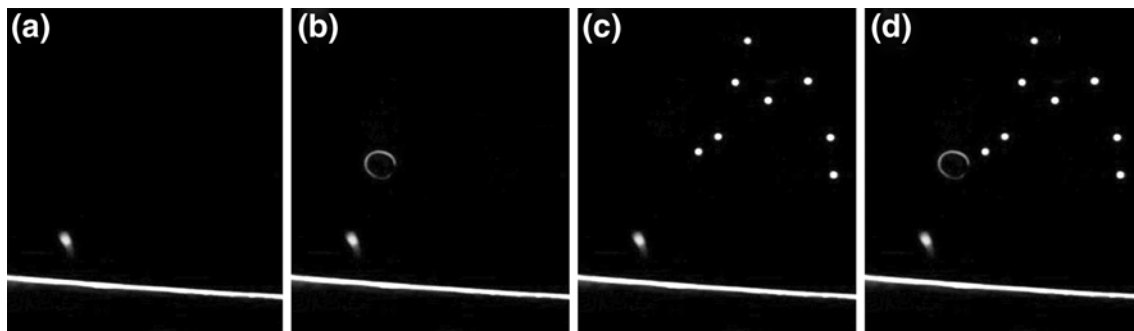


Fig. 1 Images of experimental stimulus as seen from the perspective of one of the two participants. The ball, net, and table were visible in all viewing conditions. Panel a–c shows the three different viewing conditions in Experiment 1 and 2 from the perspective of one of the

two participants. Eight experimental conditions were derived from a combination of these different viewing conditions for each participant of a pair. Panel d shows the experimental stimulus in the 'dark room' condition of the pilot study

was wearing the florescent body markers, respectively. The body markers resulted in the perception of a biological motion pattern of the player wearing the markers. In the ‘Body A + B’ condition, both participants wore the fluorescent body markers. In the ‘No Body’ condition, none of the two participants wore the fluorescent markers. From these eight conditions, we derived three factors for the statistical analysis (factor ‘own visibility’ with levels visible/invisible; factor ‘other player’s visibility’ with levels visible/invisible; and factor ‘source of information’ with levels racket/body) as outlined in Table 1.

Procedure

At the beginning of the experiment, participants were informed about the following experimental procedure. Participants played table tennis according to standard table tennis rules with the additional instruction to play the ball back and forth as often as possible between them (cooperative play). Each pair of participants played each of the eight conditions three times for a total of 24 trials. The testing order of the experimental conditions was randomized across pairs of participants. Each trial consisted of 40 passes (playing the ball from player A to player B or vice versa). The experimenter turned off the lights before each trial and turned on the lights between trials to allow the fluorescent paint to recharge. The time between trials was used to inform participants about the specifics of the next trial and to equip each player with the appropriate items (fluorescent or non-fluorescent body markers and rackets) for the upcoming experimental condition. Then, the experimenter switched off the lights and instructed one of the players to start with the serve after pressing a key on the keyboard, which resulted in playing the start sound of 2,000 Hz. Participants only started playing after hearing the start sound. The experimenter pressed the space bar on the keyboard in synchrony with the ball hitting the table to record the number of passes. The experimenter pressed either button A or B depending on who of the two players

performed an error. (The assignment of the labels A and B to participants did not change throughout the experiment and was only known to the experimenter.) Each button press resulted in a distinct tone. The participant who committed an error was then loudly saying his/her name to have the name recorded by the microphone. After the ball was recovered, the experimenter pressed the start button again (accompanied by a start sound) to indicate that the players could continue playing. The serve was alternated between the participants. The program counted the overall pass number in a trial, and once the total number had been reached, the program automatically played a stop sound to inform the participants about the end of the trial. Participants were not allowed to communicate verbally during the playing. The experiment lasted approximately 2 h.

Results and discussion

The factors for the statistical analysis coded which particular source of visual information was visible about the own or the other player’s action: source of information (body vs. racket), own visibility (visible vs. invisible), and other player’s visibility (visible vs. invisible). Importantly, the dependent variable (percentage of successful passes) was measured for each player separately.

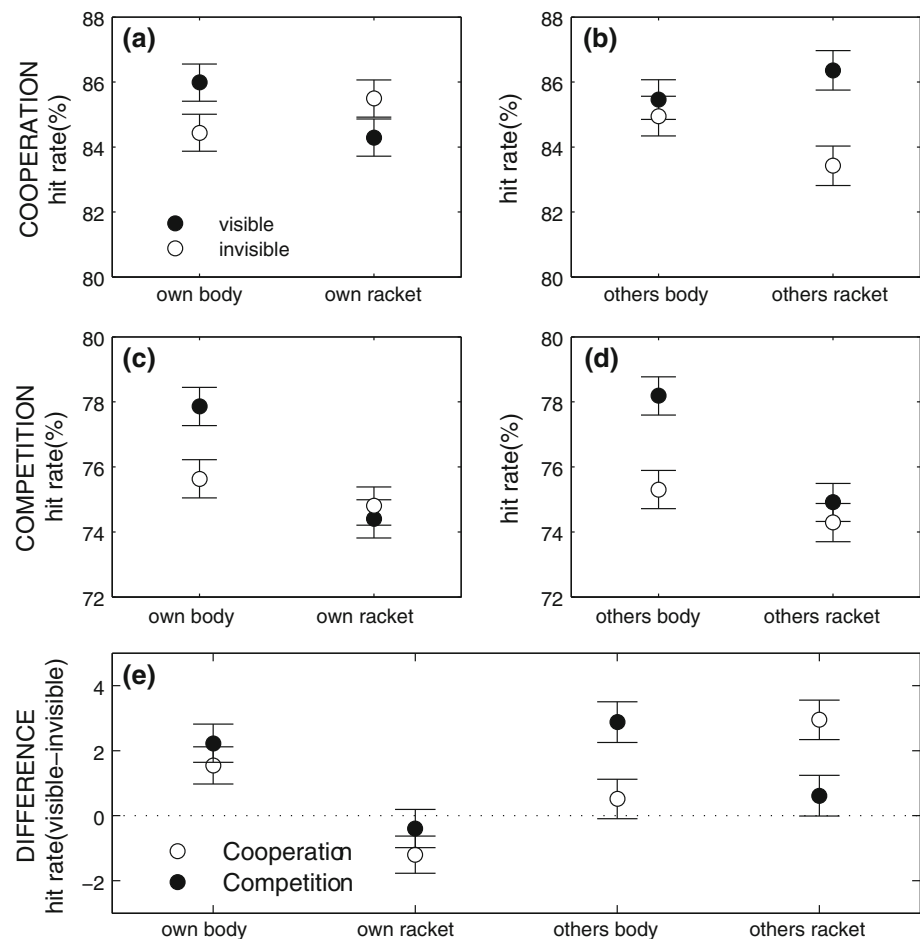
The results are shown in Fig. 2a, b. Seeing the other player’s racket and one’s own body was associated with an improvement in performance. However, the visibility of the other player’s body did not affect participants’ performance. Surprisingly, seeing one’s own racket was associated with a decrease in performance.

To investigate whether the observed effects bear statistical significance, we tested the effect of source of information, own visibility, and the other player’s visibility in a repeated measures ANCOVA. We aimed to control for the effect of the interaction partner’s performance on one’s own performance and used the interaction partner’s percentage of successful passes as a covariate. The within-subject factors of this ANCOVA were source of

Table 1 Overview of the eight experimental conditions coded with respect to the different viewing conditions as perceived by player A and player B

Conditions	Player A			Player B		
	Information	Own	Other	Information	Own	Other
Racket A	Racket	Visible	Invisible	Racket	Invisible	Visible
Racket B	Racket	Invisible	Visible	Racket	Visible	Invisible
Racket A + B	Racket	Visible	Visible	Racket	Visible	Visible
No Racket	Racket	Invisible	Invisible	Racket	Invisible	Invisible
Body A	Body	Visible	Invisible	Body	Invisible	Visible
Body B	Body	Invisible	Visible	Body	Visible	Invisible
Body A + B	Body	Visible	Visible	Body	Visible	Visible
No Body	Body	Invisible	Invisible	Body	Invisible	Invisible

Fig. 2 Mean performance scores of Experiment 1 (a, b) and Experiment 2 (c, d). The top two panels show the effect of visibility of one's own information (a) and the other player's information (b) on mean performance scores in cooperative play. The middle panels show the effect of visibility of one's own information (c) and the visibility of the other player's information (d) on mean performance scores in competitive play. The bottom panel (e) shows the difference (visible–invisible) in performance for each source of information and for both contexts (cooperative vs. competitive). Error bars indicate the standard error from the mean



information (racket vs. body), own visibility (invisible vs. visible), and the visibility of the other player (invisible vs. visible).

The ANCOVA revealed a significant main effect of the other player's visibility (visible vs. invisible), $F(1,25) = 7.19$, $\eta_{\text{partial}}^2 = 0.222$, $P = 0.013$, but no significant main effect of source of information (racket vs. body), $F(1,25) = 0.33$, $\eta_{\text{partial}}^2 = 0.013$, $P = 0.572$, and no significant main effect of own visibility (visible vs. invisible), $F(1,25) = 0.07$, $\eta_{\text{partial}}^2 = 0.002$, $P = 0.787$. There was also a significant interaction between source of information and own visibility, $F(1,25) = 8.94$, $\eta_{\text{partial}}^2 = 0.260$, $P = 0.005$, suggesting that seeing one's own racket and one's own body had different effects on playing performance. The interaction of source of information and the other player's visibility was also significant, $F(1,25) = 5.93$, $\eta_{\text{partial}}^2 = 0.183$, $P = 0.020$, indicating that seeing the other player's body and seeing the other player's racket differentially affected playing performances. The interaction between own visibility and the visibility of the other player was not significant, $F(1,25) = 2.13$, $\eta_{\text{partial}}^2 = 0.076$, $P = 0.155$. The three-way interaction between own visibility, the other player's visibility, and source of

information was also non-significant, $F(1,24) = 0.17$, $\eta_{\text{partial}}^2 = 0.007$, $P = 0.679$. There was no significant effect of the covariate, $F(24,1) = 0.33$, $\eta_{\text{partial}}^2 = 0.953$, $P = 0.569$.

Figure 2a shows the significant interaction between source of information and own visibility. Bars indicate the standard error from the mean derived from the appropriate error term of the interaction. Figure 2a shows that seeing one's own body has the opposite effect as seeing one's own racket. Paired t tests were used in order to compare the effect of seeing one's own information on performance for each source of information separately. The percentage of successful passes was significantly higher when participants saw their own body compared to when they did not see their own body, $t(25) = 2.697$, Cohen's $d = 0.182$, $P = 0.012$. On the other hand, seeing one's own racket was associated with significantly worse playing performance than not seeing one's own racket, $t(25) = 2.101$, Cohen's $d = 0.142$, $P = 0.046$.

The interaction between source of information and the visibility of the other player is shown in Fig. 2b (bars indicate standard error). Paired t tests were used in order to compare the effect of seeing the other player's information on performance for each source of information separately.

The figure shows that seeing or not seeing the other person's body did not have an effect on the percentage of successful passes which is supported by a non-significant paired t test, $t(25) = 0.838$, Cohen's $d = 0.053$, $P = 0.410$. On the other hand, seeing the other player's racket led to significantly better performance compared to when the racket was not visible, $t(25) = 4.833$, Cohen's $d = 0.306$, $P < 0.001$.

In summary, we investigated the importance of different sources of visual information about one's own and the other player's actions on individual table tennis performance in cooperative table tennis. We found the largest positive change in performance when the racket of the interaction partner was rendered visible. The positive effect of seeing the other player's racket can be explained by the improved prediction accuracy of the ball trajectory in racket sports that is associated with seeing the other player's racket (Huys et al. 2009; Mann et al. 2010; Abernethy 1990). A better prediction of the ball trajectory should lead to a better performance of hitting the ball, which in turn should result in better play. Performance also increased when one's own body was visible. Previous findings suggest that the visibility of one's own body contributes to improved online control of arm movements. The improved online control of the arm should result in increased contact with the ball, thereby increasing playing performance.

Rendering the interaction partner's body visible did not change playing performance. Previous studies suggest that different sources of visual body information lead to different prediction accuracies of an action outcome (Savelsbergh et al. 2002; Williams et al. 2002). There are several possible explanations as to why there was no improvement in performance when seeing the other player's body in Experiment 1. First, it is possible that participants did not anticipate the other player's action goals in Experiment 1. People who are cooperating often share action goals. Hence, the goals of the interaction partner are typically known in cooperative tasks. For example, players might have known that the other person will return the ball in such a way that one is able to conveniently play back the ball in the current experiment. If players know about each other's action goals in cooperative table tennis play, no or very little prediction of goals should be necessary. As a result, the visibility of the other body should have little effect. Finally, seeing one's own racket had a negative effect on playing performance. This finding is surprising since an obvious interpretation of this decrease is that seeing one's own racket is distracting.

To compare the use of visual information in cooperative and competitive contexts, Experiment 2 examined the importance of different sources of visual information in a competitive setting. Another set of participants played table tennis under the exact same conditions with the only

exception that participants were instructed to play competitively.

Experiment 2

We expected that the importance of specific sources of visual information will be modulated by the context while other sources remain equally important in a cooperative and a competitive context. Specifically, we expected that visual information about one's own body and the other player's racket will improve participants' performance for the same reasons as outlined in Experiment I. Therefore, these sources of visual information should not be affected by the context modulation.

More importantly, we hypothesized that the visibility of the other player's body is crucial in competitive table tennis. Because action goals are not aligned in competitive settings (Van Avermaet 1996), the action goals of the other player are unknown. A typical example is a penalty kick situation. Notice that the goals of the goal keeper (stopping the ball) and the kicker (scoring a goal) are not aligned. The goal keeper attempts to predict the corner to which the player will kick the ball to stop the ball, while the player possibly attempts to predict the side to which the goal keeper will jump in order to score a goal. Hence, action prediction should be much more important in competitive settings. In line with this idea, effects of social intention are larger in competitive compared to cooperative situations (Georgiou et al. 2007; Decety and Sommerville 2003). We hypothesized that participants should benefit from action prediction in competitive play, and therefore, seeing the other player's body should be important in competitive play.

As in Experiment 1, we assessed the effect of the visibility of one's own and the other player's racket and body on the number of successful passes.

Method

The methods of Experiment 2 were identical to those of Experiment 1 with the following exceptions.

Participants

There were 14 pairs of participants (mean age: 28.18; sd: 3.32). All participants were right-handed, and all had normal or corrected-to-normal vision. Participants were recruited from the Max Planck Institute Subject Database and were naive with respect to the purpose of the study. This research was performed in accordance with the ethical standards specified by the 1964 Declaration of Helsinki. All participants gave their informed consent prior to the experiment and received 8 Euros per hour for their participation.

Procedure

In Experiment 2, participants were instructed to play table tennis competitively by informing them that the participant with the least amount of errors would win the trial. There was no financial reward associated with winning a trial.

Results and discussion

Experiment 2 set out to examine the effect of seeing one's own racket or body and seeing the other player's racket or body on the percentage of successful passes when table tennis is played competitively. The results of this experiment are shown in Fig. 2c, d. Seeing one's own and the other player's body seems to improve performance. Furthermore, seeing one's own and the other player's racket seems to have no impact on performance.

We examined the effect of source of information (racket vs. body), own visibility (visible vs. invisible), and other player's visibility (visible vs. invisible) on percentage of successful passes in a three-factorial complete within-subject ANCOVA with the percentage of successful passes of the interaction partner as a covariate.

The ANCOVA revealed significant main effects of the visibility of the other player (visible vs. invisible), $F(1,27) = 10.57$, $\eta^2_{\text{partial}} = 0.283$, $P = 0.003$, and source of information (body vs. racket), $F(1,27) = 13.51$, $\eta^2_{\text{partial}} = 0.307$, $P = 0.001$, but no significant effect of own visibility (visible vs. invisible), $F(1,27) = 1.46$, $\eta^2_{\text{partial}} = 0.038$, $P = 0.236$. The interaction between source of information and own visibility was significant, $F(1,27) = 9.67$, $\eta^2_{\text{partial}} = 0.263$, $P = 0.004$. The interaction between source of information and the other player's visibility also turned out significant, $F(1,27) = 5.78$, $\eta^2_{\text{partial}} = 0.171$, $P = 0.022$. The interaction between own visibility and the other player's visibility was not significant, $F(1,27) = 0.20$, $\eta^2_{\text{partial}} = 0.007$, $P = 0.660$. The three-way interaction between the factors own visibility, the other player's visibility, and source of information was also non-significant, $F(1,26) = 0.62$, $\eta^2_{\text{partial}} = 0.023$, $P = 0.439$. There was also a significant effect of the covariate, $F(26,1) = 15.45$, $\eta^2_{\text{partial}} = 0.110$, $P = 0.001$.

The significant interaction between source of information and own visibility is shown in Fig. 2c. Paired t tests were used to compare the effect of visibility of one's own information on performance for each source of information separately. Performance scores significantly improved when participants saw their own body compared to when their own body was invisible, $t(27) = 3.816$, Cohen's $d = 0.233$, $P < 0.001$. One explanation of this result is that the visibility of one's own body leads to improved action coordination. We observed no significant change in performance when the visibility of one's own racket changed, $t(27) = 0.685$, Cohen's $d = 0.042$, $P = 0.499$. Figure 2d shows a

significant interaction between source of information and the visibility of the other player. Paired t tests were used to compare the effect of visibility on performance for the other player's racket and the other player's body separately. The visibility of the other player's body led to an increase in the percentage of successful passes, $t(27) = 4.585$, Cohen's $d = 0.262$, $P < 0.001$, while seeing the other player's racket did not lead to significant changes in performance, $t(27) = 0.991$, Cohen's $d = 0.057$, $P < 0.331$. The result that visual information about the opponent improved playing performance supports our hypothesis that action prediction is critical in competitive play.

In a next step, we directly compared Experiments 1 and 2 to determine the effect of social context on the importance of different sources of visual information.

Comparing cooperative and competitive play

We directly compared the results of Experiments 1 and 2 to estimate the effect of social context on the importance of different sources of visual information. A comparison of Fig. 2a–d shows that cooperative play was associated with an overall higher performance than competitive play. Furthermore, a comparison of the critical interactions in both experiments revealed that participants profited from seeing the other player's racket but not the other player's body in cooperative play (Fig. 2b), whereas in competition participants profited from seeing the other player's body but not the other player's racket (Fig. 2d).

To directly assess how social context modulates performance associated with the visibility of different sources of visual information, we calculated the difference in the percentage of successful passes between visible and invisible conditions for each source of information and social context separately (Fig. 2e). Positive differences indicate that the visibility of the information improved the percentage of successful passes, while negative differences indicate a decrease in performance. Interestingly, the visibility of the participant's own racket and body led to similar performance changes in cooperative and competitive conditions. This suggests that social context did not change the importance of visual information about one's own movements. However, the pattern of results diverged regarding the visibility of visual information about the other player. Visibility of the other player's racket improved performance only in the cooperative condition, whereas visibility of the other player's body improved performance only in the competitive condition. This indicates that social context modulates the importance of different sources of visual information.

To test whether this pattern bears statistical significance, we compared the results of Experiments 1 and 2 in one overall analysis. Specifically, we carried out an ANCOVA

with context (competitive vs. cooperative) as a between subject factor and source of information, own visibility, and the other player's visibility as within-subject factors. The performance of the other player was used as a covariate.

We found significant main effects of context (cooperative vs. competitive), $F(52,1) = 24.65$, $\eta_{\text{partial}}^2 = 0.032$, $P < 0.001$, the other player's visibility (visible vs. invisible), $F(52,1) = 19.32$, $\eta_{\text{partial}}^2 = 0.272$, $P < 0.001$, and source of information (tool vs. body), $F(52,1) = 8.29$, $\eta_{\text{partial}}^2 = 0.126$, $P = 0.006$, but no significant effect of own visibility (visible vs. invisible), $F(52,1) = 1.81$, $\eta_{\text{partial}}^2 = 0.025$, $P = 0.182$. The interaction between context and the other player's visibility was not significant, $F(52,1) = 0.01$, $\eta_{\text{partial}}^2 < 0.001$, $P = 0.912$. The interaction between context and own visibility was also not significant, $F(52,1) = 0.40$, $\eta_{\text{partial}}^2 = 0.007$, $P = 0.531$. Furthermore, there was no significant interaction between context and source of information, $F(52,1) = 2.90$, $\eta_{\text{partial}}^2 = 0.046$, $P = 0.094$. Also, the interaction between the other player's visibility and source of information turned out to be non-significant, $F(52,1) = 0.11$, $\eta_{\text{partial}}^2 = 0.002$, $P = 0.744$. The interaction between the other player's visibility and own visibility turned out to be non-significant as well, $F(52,1) = 2.92$, $\eta_{\text{partial}}^2 = 0.051$, $P = 0.093$. On the other hand, the interaction between own visibility and source of information was significant, $F(52,1) = 2.92$, $\eta_{\text{partial}}^2 = 0.196$, $P = 0.001$, indicating a performance difference associated with seeing one's own body and seeing one's own racket. The interaction between context, own visibility, and source of information, $F(54,1) = 0.24$, $\eta_{\text{partial}}^2 = 0.004$, $P = 0.629$, however, was not significant.

Importantly, the interaction between context, the other player's visibility, and source of information was significant, $F(52,1) = 6.00$, $\eta_{\text{partial}}^2 = 0.103$, $P = 0.018$, suggesting that the social context had a differential effect on how the visibility of the other player's information (body vs. racket) affected table tennis performance. This result is in line with our hypothesis that social context modulates the importance of the visual information about the other person. Finally, there was no significant three-way interaction between the other player's visibility, own visibility, and context, $F(52,1) = 1.24$, $\eta_{\text{partial}}^2 = 0.022$, $P = 0.271$, no significant 3-way interaction between the other player's visibility, own visibility, and source of information, $F(52,1) < 0.001$, $\eta_{\text{partial}}^2 < 0.001$, $P = 1.000$, and no significant 4-way interaction between context, the other player's visibility, own visibility, and source of information, $F(52,1) = 0.73$, $\eta_{\text{partial}}^2 = 0.014$, $P = 0.396$. There was also a significant effect of the covariate, $F(51,1) = 6.85$, $\eta_{\text{partial}}^2 = 0.940$, $P = 0.012$.

It could be that the differential effect of seeing the other player on table tennis performance in Experiments 1 and 2 was due to differences in playing speed rather than

differences in social context. If players played faster in the competitive than in the cooperative conditions, they might have had less time to prepare their own strokes in the competitive condition. It is possible that participants might have looked for early cues about how the other player plays the ball by focusing on the other player's body cues. Indeed, participants played significantly faster in the competitive (mean pass duration = 722 ms; SD = 8.0 ms) than in the cooperative conditions (mean pass duration = 923 ms; SD = 13.0 ms), as revealed by an independent between samples t test, $t(52) = 6.89$, $P < 0.001$. To see whether the modulation of the other player's information by social context can be explained by playing speed, we used the playing speed as measured by the pass duration as a covariate. The pass duration is the time between the moments when the player hits the ball to when the interaction partner hits the ball. We calculated the average pass duration for each trial and used this data as a covariate in the previous analysis. If the modulation of the import sources of visual information about the interaction partner was due to different playing speeds in different contexts, we expect the interaction between context, visibility of the other player, and source of information to be no longer significant.

We ran the previous analysis, which compared Experiments 1 and 2, in exactly the same way with pass duration as an additional covariate. For sake of clarity, we limit the report of this analysis to the critical interactions. The interaction between context, the other player's visibility, and source of information was significant, $F(54,1) = 6.14$, $P = 0.017$, again suggesting that social context modulated how the visibility of the other player's information affected performance. The interaction between context, own visibility, and source of information was not significant, $F(54,1) = 0.26$, $P = 0.601$. The significant three-way interaction between source of information, the other player's visibility, and context suggests that different playing speeds in the two social contexts cannot explain the differences in how the visibility of the other player's information affected table tennis performance.

In summary, the direct comparison of Experiments 1 and 2 shows that social context modulates the importance of the others player's visual information. This result cannot be explained by the faster playing in the competitive condition alone.

Discussion

In the current study, we sought to examine how different sources of visual information affect table tennis performance in different social contexts. We therefore manipulated the visibility of one's own racket, one's own body,

the racket of the other player and the body of the other player in a cooperative (Experiment 1) and competitive (Experiment 2) table tennis settings. The results showed that social context had a differential effect on table tennis performance depending on whether information about oneself or the other player was rendered visible. Manipulating the visibility of visual information about oneself had the same effect on table tennis performance in a competitive context and in a cooperative social context. However, social context affected how information about the other player was used. Specifically, in the cooperative setting, the most pronounced performance increases occurred when the other player's racket was rendered visible. In contrast, in the competitive condition, rendering the other player's body visible was associated with the largest positive performance changes. This suggests that different sources of visual information are used in competitive and cooperative contexts. Overall, these results suggest that social context affects the importance of visual information about others.

Our results argue against the idea that the effects of social context on playing performance merely reflect the effect of the different playing speeds in cooperative and competitive play. When including playing speed as a covariate in the analysis, we found the same effects as in the analysis without playing speed as a covariate. We therefore deem it unlikely that playing speed is the sole mediator for the observed effect.

Our findings indicate that action prediction is more important in competitive than in cooperative play. As the goals of interaction partners align in cooperative play interaction, partners can easily predict each other's actions. In contrast if the goals are not aligned (as in competitive play), action goals need to be inferred. Thereby, visual body information might serve as an important source of information. In line with this suggestion, it has been shown that humans are able to infer intentions from point light stimuli (Runeson and Frykholm 1983; Barrett et al. 2005) and intentions influence behavior more strongly in competitive than cooperative settings (Georgiou et al. 2007).

A possible alternative explanation for the finding that body information was more important in Experiment 2 than in Experiment 1 is that players in Experiment 2 may have been more experienced. Previous findings have shown that expert players focus on different parts of their partner's body during the anticipation of an action compared to novices and that they are better at predicting action outcomes (Savelsbergh et al. 2002; Williams et al. 2002). We therefore compared the experience of players between the two experimental groups. We measured table tennis experience of participants in terms of the amount of time participants played table tennis in the past year. The two samples *t* test revealed no significant differences in table tennis experience between the two groups, $t(40) = 1.73$,

$P = 0.091$. Hence, motor expertise alone cannot explain our findings.

Because action goals are known in cooperative play, players might focus on different aspects of the task to improve the attainment of their action goals. For example, players might have focused on the exact prediction of the ball trajectory in the cooperative condition to ensure that they play the ball in a way that it is optimal for the other player. Because the orientation of the racket and the angle of incidence is important to calculate the angle of reflection seeing the other player's racket might have become important.

Furthermore, we found that participant's performance improved when one's own body was visible but not when one's own racket was visible, independently from the social context. In line with previous research, visual information about one's own body might have contributed to improved online control of arm movements which resulted in increased playing performance. The absence of an effect of seeing one's own racket might have been due to the orientation of the racket in the participant's hand. As mentioned above, seeing the racket might be important for predicting the ball trajectory (angle of reflection equals angle of incidence). However, the predictability strongly depends on the viewing angle. Participants saw their own racket in the periphery only and the viewing angle might be very inconvenient to make physical predictions about the ball trajectory. Therefore, participants might not have been able to use visual information about their own racket in order to facilitate their playing performance.

In order to investigate the effect of social context on the use of visual information, we employed a novel experimental paradigm which takes into account the perceptual and motor interdependencies between two individuals performing a social interaction task. In the past, researchers often investigated the processing of social stimuli in isolated individuals. For instance, researchers in sport sciences investigated the importance of perceiving visual information about opponent player's actions using psychophysical methods. In most of these studies, participants were asked to judge the fate of an action (e.g., a tennis shot) which was previously video recorded and finally displayed on a computer screen (Huys et al. 2009; Aglioti et al. 2008, Abernethy 1990). The authors used spatial and temporal occlusion to test the effect of visibility on participant's prediction accuracy. The advantage of using psychophysical methods to examine human's ability to pick up task relevant information is the high degree of control and thus statistical power. However, it is not clear in how far this paradigm accounts for real-life interactions in which two or more individuals influence each other's actions and are set in a common social context. The investigation into social interaction behavior under real-life

conditions allowed for a more realistic assessment of the critical sources of visual information. Our findings point to a novel factor that influences the use of visual information. So far, studies have shown that novices and experts focus on different sources of visual information, suggesting that motor expertise is a critical factor in the use of visual information (Aglioti et al. 2008; Calvo-Merino et al. 2005; Keller et al. 2007; Casile and Giese 2006). Here, we demonstrated that social context also modulates the importance of different sources of visual information.

Acknowledgments We would like to thank Megan McCool for fruitful discussions and proof reading of the manuscript and Magdalena Leshtanska for part of the data recording. We gratefully acknowledge the support of the Max Planck Society and the WCU (World Class University) program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology (R31-2008-000-10008-0). Natalie Sebanz acknowledges the support from a European Young Investigator Award by the European Science Foundation. The contribution of Stephan de la Rosa was funded by the EU Project TANGO (ICT-2009-C 249858).

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