TITLE: Motor coordination and strategic cooperation in joint action

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ABSTRACT

Naturalistic joint action usually requires both motor coordination and strategic cooperation. However, these two fundamental processes have systematically been studied independently. We devised a novel collaborative task, combining different levels of motor noise with different levels of strategic noise, to determine whether sense of agency (the experience of control over an action) reflects the interplay between these low-level (motor) and high-level (strategic) processes. We also examined how dominance in motor control could influence prosocial behaviours. We found that self-agency was particularly dependent on motor cues while joint agency was particularly dependent on strategic cues. We suggest that the prime importance of strategic cues for joint agency reflects the co-representation of co-agents' interests during the task. Furthermore, we observed a reduction of prosocial strategies in agents who exerted a dominant motor control over the joint action, showing that the strategic dimension of human interactions is also reliant on low-level motor features.

Keywords: joint action; motor coordination; strategic cooperation; economic games; sense of agency; prosocial strategies; leadership.

STATEMENT OF RELEVANCE

Voluntary action has long been studied through its motor components, without considering the strategic dimension existing in the case of social interactions. In the present study, we reconciled the experimental fields of voluntary action and social decision-making by devising a collaborative task combining different levels of motor noise (turbulences) with different levels of strategic noise (economic games). On the one hand, we inspected how sense of agency (the experience of control over a voluntary action), could reflect the interplay between motor and strategic processes. On the other hand, we analysed how motor control could also impact prosocial strategies. Thus, these data are of primary importance for understanding the cognitive and psychological processes underpinning naturalistic joint action. Beside the scientific field of human action and agency, this study could also be of particular interest for social psychologists and game theorists since it provides additional information about human cooperation and social decision-making.

1. INTRODUCTION

Over the last decades, human voluntary action has generally been studied in isolation, through individual experimental settings (e.g., Charles, & Haggard, 2019; Le Bars et al., 2019). However, in our ultra-social world, agents rarely act in complete isolation but recurrently coordinate their actions with others in order to achieve shared goals (Sebanz et al., 2006; Pacherie, 2013; Vesper et al., 2017), following strategic rules that aim at maximizing the ‘expected utility’ of these actions. Such rules have been widely modelled by game theory and neuroeconomics (Von Neumann & Morgenstern, 1947; Tremblay, Sharika & Platt, 2017). Nevertheless, the specific relation existing between motor (action control) and strategic strata (action purpose) has long been ignored (see Mudrik et al., 2019). For instance, in the field of joint action, the study of motor coordination still prevails (e.g. Török et al., 2019; Abe et al., 2019). In parallel, behavioural economics have constantly overlooked the impact of low-level motor processes on social decision-making models (see Kleiman-Weiner et al., 2016). Thus, a considerable number of questions remains unanswered regarding the potential interplay between joint motor control and strategic cooperation in naturalistic and meaningful interactions.

In particular, the sense of agency (SoA) – a subjective feeling typically associated with voluntary action in the first person (Haggard & Chambon, 2012; Moore, 2016) – has never been studied in the context of strategic interactions. From a neurocognitive perspective, individual SoA would result from two complementary retrospective and prospective processes (see Haggard, 2017). Firstly, SoA is supposed to retranscribe *retrospectively* the level of match between the actions’ consequences predicted by a forward model and the actual sensory reafferences (see Wolpert et al., 1995). Thus, individual SoA would be disturbed in case of comparison discrepancies (i.e. prediction error) at the sensorimotor level. Secondly, it has been shown that the fluency of action selection could also *prospectively* affect the sense of agency over individual action outcomes (Chambon & Haggard, 2012). While both retrospective and prospective components of individual SoA have been much scrutinized, the specific mechanisms contributing to the SoA in coordination tasks remain unclear (e.g. Obhi & Hall, 2011; Dewey, Pacherie & Knoblich, 2014; Bolt et al., 2017). The co-representation of the co-agent’s intentions (see Sebanz, Knoblich, & Prinz, 2003) could be an essential prerequisite for experiencing joint

agency. Thus, exploring the potential transformation of agentic awareness and identity, from a sense of individual agency to a sense of joint agency (see Pacherie, 2012; Bolt, Poncelet, Schultz & Loehr, 2016), is particularly intriguing within strategic joint action where the co-agents' intentions are not fully aligned.

In a series of novel and naturalistic tasks inspired from recent experiments (Dewey et al., 2014; Le Bars et al., 2020), we instructed dyads of participants to coordinate their actions online in order to move a cursor and ultimately reach one of several targets, without communicating. Importantly, the experiments were designed so as to combine different levels of motor noise – operationalized through random deviations applied on the cursor's moves – with different levels of strategic noise – operationalized through 3 types of economic games (see fig.1). In a first type of game exempted from strategic noise, there was only one target of interest offering equal gains for both players whose proximal (reaching the target) and distal intentions (obtaining the gains) were thus presumably aligned. The second type of game consisted in a pure coordination game with low strategic noise since the two targets of interest contained similar and symmetric gains for both players, resulting in aligned distal intentions but potentially conflicting proximal intentions. The last type of game consisted in a highly competitive situation with high strategic noise, commonly named Battle of Sexes (BoS) (see Colman, 2016). The two targets of interest contained asymmetric gains causing partially divergent interests in players, leading to potentially conflicting distal and proximal intentions. In a second block-wise experiment, we also manipulated the order of the games (coordination first vs. competition first) in order to assess whether presentation order could influence SoA judgments and prosocial strategies, as previously suggested (see Michael et al., 2016).

Because *leadership* has been associated to inconsistent effects in joint agency (see Obhi et al., 2011; Bolt et al., 2016; Le Bars et al., 2020), we additionally implemented three conditions of motor leadership via the spatial configuration of the two targets of interest in both the pure coordination game and the BoS game (see fig.2). Thus, either both agents kept their ability to choose in which direction to go (i.e. equal leadership) or only one agent maintained this ability, making that agent the leader and the co-agent the follower.

After each trial, participants had to rate their feelings of individual and collective control over the joint action (Le Bars et al., 2020). Both types of judgment

were collected to disentangle the weight of low- (motor) and high- (strategic) level processes associated to self and joint agency (see Tuomela, 2006; Pacherie, 2012; van der Wel et al., 2015).

We hypothesized that both motor and strategic noise would differently influence sense of self- and joint agency. More precisely, we predicted that motor noise would specifically and primarily impede sense of self-agency, which is supposed to strongly rely on internal sensorimotor cues (e.g. Metcalfe, Eich & Miele, 2013; Moore, 2016; Sidarus et al., 2017). In contrast, we expected judgments of joint agency to be less pervious to motor noise, notably because the internal motor states of the co-agent are not directly available to the agent (Pacherie, 2012). Moreover, if joint agency relies on the co-representation of others' intentions, the situations where players' distal intentions are not aligned (BoS) should reduce joint agency, making it particularly vulnerable to high-level strategic noise. In sum, we should observe a stronger impact of low-level motor processes on self-agency and a stronger impact of high-level strategic processes on joint agency.

Finally, in addition to exploring the interplay between low-level (motor noise) and high-level (strategic noise) processes on SoA, we also investigated how the prosocial or selfish strategies observed in BoS situations could be influenced by the joint task parameters such as games' order and motor leadership. We predicted that the number of intended prosocial behaviours would rise when participants started with the coordination games rather than the competitive games (BoS), due to an increased commitment to the joint task (see Wiltermuth & Heath, 2009; Michael et al., 2016). We also expected that dominant leadership, implemented in terms of motor lead, would generate an increase in selfish behaviours relative to equal leadership conditions, demonstrating that strategic decisions are shaped by motor parameters (see Kleiman-Weiner et al., 2016).

2. METHOD

2.1 Participants

Based on a previous experiment (see Le Bars et al., 2020), we estimated the power of the motor noise fixed effect on judgments of collective control by simulating 100 random samples with simR (Green, MacLeod & Alday, 2016). For N trials = 192, we determined N participants ≥ 16 for each subgroup in order to ensure a satisfying statistical power ($[1 - \beta] = 95\%$; IC[88.72; 100]) and a good replicability rate for this factor. Then, we recruited 100 adults to constitute 50 same-gender dyads who were split into the experimental subgroups: 40 participants (20 teams, 22 females, Age = 26.92 ± 4.36) were assigned to the first study where the three levels of strategic noise were randomly mixed within the blocks; and 60 participants (30 teams, 48 females, Age = 22.84 ± 4.30) were assigned to the second study where levels of strategic noise were implemented into separate blocks, with one group of 30 participants (15 teams, 26 females, Age = 22.30 ± 3.97) starting with pure cooperative blocks while the other group began with competitive blocks (15 teams, 22 females, Age = 23.43 ± 4.63). One team was removed from the second study's analysis because a player left the experiment before it was completed, leaving 98 participants (49 teams, 58 females, Age = 24.49 ± 4.72) in the final sample.

Age difference between teammates was controlled to not exceed 10 years (mean age difference in dyads = 4.94 ± 3.60). We also ensured that teammates did not know each other before the experimental session and they were not allowed to communicate until the end of the task. Participants were all right-handed, neurologically healthy individuals, with normal or corrected-to-normal vision. Participants provided written informed consent and were compensated with money according to their overall performances (i.e. from 15 euros to 30 euros). This study was performed in accordance with the declaration of Helsinki and the Comité de Protection des Personnes (CPP) Ile de France II granted ethical approval.

2.2 Material

Both players of each dyad sat next to each other at a table, with an approximate distance of 50cm between them. They were separated by a divider fixed in the middle of the table and they both wore headphones playing white noise in order to prevent any kind of communication. The participant located on the left of the divider was referred to as the “player 1” and the participant located on the right referred as “player 2” during the whole experiment. Two similar LCD 19” monitors (1280x1024 at 60Hz), one on either side of the divider, displayed the same duplicated image at a viewing distance of approximately 60 cm from each player. Partners also had their own keyboard to complete the task and to respond to the questions with the right hand, without being seen by the other player. We positioned stickers representing arrows (i.e. up, down, left or right) on the relevant keys to facilitate their identification. We used Matlab R2016b and the Psychophysics Toolbox Version 3 (PTB-3) (Brainard, 1997; Pelli, 1997; Kleiner et al, 2007) to write and run the joint task.

2.3 The joint task

In the joint motor task, communication between partners was not allowed. Players were asked to coordinate their actions online in order to move a cursor from the centre of the screen up to a specific square (i.e. the target), before the end of the timer countdown. One of the two partners could only move the cursor in the vertical direction (y-axis) while the other partner could only move it in the horizontal direction (x-axis), making teams’ motor coordination essential to carry out the task. Players were told that the computer could generate some random deviations in the trajectory of the cursor, making the trials more or less difficult to achieve (Figure 1). Participants were also instructed to choose the target based on the amount of points displayed in the squares, and were explicitly told that these points would be converted into money at the end of the experiment. Crucially, the targets’ payoffs could be either equal or unequal for both players, making players’ interests respectively congruent or divergent. The participants were not informed that the experiment was designed to provide the exact same gains opportunities to both players. At the end of each trial, partners were invited to independently rate their

“feeling of individual control” and their “feeling of joint control” over the cursor’s movement.

2.4 Procedure & stimuli

2.4.1 Questionnaire

Before the task, participants completed the abbreviated version of the Singelis scale (Singelis et al., 1995; Triandis & Gelfand, 1998) in order to get an individualism-collectivism score.

2.4.2 Training phase

The experiment started with a training session, which aimed at familiarizing the participants with the basics of the task. It consisted in one block of 20 trials where participants were instructed to reach the square containing the highest score (e.g., “3”), by moving the cursor with key presses, as fast as possible. Players performed this training session alone, each in turn. Thus, unlike the main task, participants were able to move the cursor on both vertical and horizontal axes, that is, left and right (with K and L keys) and up and down (with Q and W keys) by using both hands. Moreover, there was no random deviation applied on the cursor trajectory and no strategic noise since there was only one target of interest.

2.4.3 Experimental phase

The individual training phase was immediately followed by the joint task. The first study was made of 8 blocks of 36 trials (i.e. 288 trials overall) while the second study, which contained fewer factors levels, was made of 6 blocks of 32 trials (i.e. 192 trials overall). Before each block, the instructions’ screen was displayed during 5 seconds and informed players about which buttons to press – which axis to control – during the forthcoming block. The axes to be controlled were reversed after each block to make sure that the two partners equally controlled both directions at the end of the experiment.

During the first study, the levels of motor noise (i.e. the random deviations), strategic noise (i.e. game with convergent or divergent interests) and leadership were mixed within the blocks. During the second study, the levels of motor noise and

leadership were also mixed within the blocks but levels of strategic noise were blocked in order to dissociate contexts of cooperation and contexts of competition: half of the teams started with 3 “cooperation” blocks followed by 3 “competition” blocks, while the other half started with 3 “competition” blocks followed by 3 “cooperation” blocks.

2.4.4 Trials timeline & factors

At the beginning of each trial, a square coloured with a random mixture of grey shades appeared at the centre of the screen while 4 peripheral uniform grey squares (sides = $90\text{px} \times 0.294\text{mm} = 2.65\text{cm}$), namely the targets T , were arranged symmetrically along both X and Y axes originating from the screen centre 0 (i.e. $OT_x = 12.5\text{cm}$; $OT_y = 12.5\text{cm}$). The four peripheral targets were labelled with small white numbers on their tops. Crucially, all targets also contained two scores separated by a dot. Those scores ranged from 0 to 3 and participants were instructed that their gains would depend on these numbers. Participants were also told that points being on the left of each target were assigned to player 1 and points on the right of each target were assigned to player 2. For example, if the team reached a target indicating “2.2”, each player earned 2 points. If the team reached a target indicating “2.3”, the player 1 earned 2 points and the player 2 earned 3 points. Based on this information, participants were asked to provide an initial choice about the target they would like to reach, by reporting the corresponding target’s label with their keyboards. Once both participants had reported this initial choice, the white targets’ labels disappeared, and after a 500-ms delay, the white cursor (diameter = $15\text{px} \times 0.294\text{mm} = 4.41\text{mm}$) materialized in the central square simultaneously with the 7-second countdown located on the top of the screen. In each team, one participant was able to move the cursor vertically (i.e. along the X-axis) using K (left) and L (right) keys of an AZERTY keyboard, while the other teammate was able to move the cursor horizontally (i.e. along the Y-axis) using Q (up) and W (down) keys. Thus, online coordination between both agents was crucial to successfully move the cursor from the centre of the screen to the target(s). Each key press produced a 6px (i.e. 0.18cm) move of the cursor on the axis that was controlled by the player (e.g., “K” press moves the cursor 6px to the left) and also moved the cursor by 0 to 4.5 px on the other axis (i.e. controlled by the other player) in order to generate some deviations in the expected trajectory of the cursor (motor noise condition). The same amount of deviation was

applied to both players' key presses. The effects of the key presses were continuous, immediate and added to each other. Thus, the actual cursor's moves resulted from the vector combination of both trajectories produced by the players' key presses.

If a rewarding square (i.e. a target with a score > 0 points for at least one of the players) was reached before the end of the countdown, the cursor disappeared and the target was framed in green during 200ms, meaning that the trial was successful. On the contrary, if a null square (i.e. a target with a score $= 0$ points for both players) was reached, the cursor disappeared and the distractor was framed in red during 200ms. If no target was reached within the time limit, the cursor disappeared but the squares remained on the screen during 200ms. In those two last situations, trials were counted as failed.

Motor noise factor. To manipulate the sensorimotor dimension of the joint action (i.e. the players' motor intentions), some random deviations were applied to the trajectory of the cursor. In the first study, we used 3 levels of motor noise: 1/3 of trials were exempt from motor noise (i.e. 0 px of deviation); 1/3 of trials were subject to slight deviations (i.e. from 1px to 2px of deviation in the orthogonal direction of the expected trajectory); and 1/3 of trials were subject to higher deviations (i.e. from 3.5px to 4.5px of deviation in the orthogonal direction of the expected trajectory). In the second study, we only used the 2 motor noise levels corresponding to the no motor noise and high motor noise conditions. In both studies, the trajectory deviations could be positive (50% of trials) or negative (50% of trials), meaning that they could be congruent (e.g., target on the right, deviation on the right) or incongruent with the actual direction to the target.

Strategic noise factor. To induce some noise at the social decision or strategic level of the joint action, we employed different types of games in order to manipulate the convergence/divergence of players' interests, corresponding to players' distal intentions. Participants were instructed that gains on the left of each target were for player 1 and gains on the right of each target were for player 2. On this basis, we used three different levels of strategic noise in the first study (see fig.1): 1/3 of trials were exempt from any strategic noise or conflict because there was only one target of interest (i.e. a target with score > 0 point for both players) containing similar gains for both players, while the three remaining targets were linked to null payoffs for both players; 1/3 of trials consisted in motor coordination games where two targets among the four squares were of similar interest, with similar gains for the two players, while

the two remaining targets were linked to null payoffs for both players; 1/3 of trials consisted in typical Battle of Sexes games where two targets were of potential interest but contained unequal payoffs (i.e. the player 1 would earn more with one of the two targets of interest while the player 2 would earn more with the other target of interest), while the two remaining targets were linked to null payoffs for both players. In the second study, we only used the 2 levels of strategic noise corresponding to the low strategic noise (i.e. two similar targets with similar payoffs for both players) and high strategic noise conditions (i.e. the battle of Sexes configuration with two targets of interest exhibiting different payoffs for both players). In both studies, the individual gains ranged from 0 to 3. Thus, in situations of equal gains across players (i.e. situations of no strategic noise or low strategic noise) the targets of interest could contain the following payoffs: 1.1, 2.2 or 3.3. In the Battle of Sexes configuration, the difference in players' gains within the same target was always equal to 1 point and the two targets of interest were symmetrical so that they could contain the following payoffs: 0.1 & 1.0; 1.2 & 2.1, 2.3 & 3.2.

Fig. 1., Trial examples from the joint task. In these 3 examples, player 1 is controlling the X-axis while player 2 is controlling the Y-axis. At the beginning of each trial, each player confidentially provides her first intention concerning the target to reach among the four squares displayed on screen. Each target contains two scores separated by a dot. The score on the left represents the potential individual gain for the player 1 (located on the left) while the score on the right represents the potential individual gain for the player 2 (located on the right). After the choice phase, the cursor to be moved and the timer appear on screen. **A.**, There is only one target of interest (3.3), which corresponds to the condition with no strategic noise; here the induced motor noise is high. **B.**, There are two targets of interest that both contain the exact same gains (2.2) for both players, which corresponds to condition with low strategic noise (i.e. convergent interests); here, the induced motor noise is absent. **C.** There are two targets with divergent interests for both players (3.2 or 2.3), which corresponds to the Battle of Sexes (BoS) strategic configuration, that is, if players manage to reach a target, one player will earn more points than the other. The induced motor noise is intermediate. When a target is reached by the cursor before the end of the countdown and earns points to the players, it is framed in green during 500ms if it provided some points to the players. *N.B.*: please note that stimuli size (e.g., targets, cursor, etc) has been enhanced relative to the screen size for presentation purpose.

Leadership factor. In situations where there were two targets of interest (i.e. in pure coordination games and in Battle of Sexes games), we induced some “spatial leadership” by controlling the locations of these two targets (see figure fig.2). In fact, when the two targets of interest were diametrically opposed on both X- and Y- axes, both players kept the possibility to direct the cursor in one or the other direction to reach their preferred target, depending on the gains and the dimension they were in charge of (i.e. the player responsible for the X-axis could choose to go left or right and the player responsible for the Y-axis could choose to go up or down), which conferred equal leadership to both players. Nevertheless, when the two targets of interest were opposed on one axis only, only the player responsible for this particular axis kept the possibility to direct the cursor toward one or the other target, making her/him the leader of that trial. In such contexts, the player responsible for the other axis became a follower or a simple contributor to the joint action. In sum, by manipulating the spatial arrangement of the two targets of interest we implemented 3 motor roles: leader, follower, and balanced roles.

Fig. 2., Leadership configurations. In these 3 examples, player 1 is controlling the x-axis while player 2 is controlling the y-axis. Roles (leader vs. follower) are determined by the spatial layout of the two targets of interest, according to the axis that each player controls. **A.**, Both targets of interest are opposed on both axes leaving the two players initially free to choose in which direction to move the cursor (i.e. left or right for player 1; up or down for player 2). **B.**, Both targets of interest are opposed on the y-axis only, leaving the player 2 free to choose in which direction to go (i.e. up or down). However, the player 1 (x-axis) is logically bound to choose the only direction leading to the two targets of interest (i.e. the left direction). **C.**, Both targets of interest are opposed on the x-axis only, leaving the player 1

free to choose in which direction to move the cursor (i.e. left or right) while the player 2 is bound to choose the only direction leading to the two targets of interest (i.e. the up direction). N.B.: please note that stimuli size has been enhanced and targets of interest have been framed in white for presentation purpose only.

Judgments of Feeling of Control (JoC). In line with a previous experiment (see Le Bars et al., in press), participants were asked two questions concerning their JoC at the end of each trial. One question evaluated their individual JoC and was expressed in the following way: “How much did you feel *individually* in control of the cursor’s movement?”. The other question assessed their joint JoC and was formulated as: “How much did you feel *together* in control of the cursor’s movement?”. Both questions were asked in French, which allowed us to further stress the difference between the individual and the collective JoC by using the personal pronouns “tu” (second-person singular) and “vous” (second-person plural). The order of these two questions was randomized so that each question was presented an equal number of times as the first or the second question. Participants were instructed to answer both questions, one after the other, by using a 9-point scale where “1” meant that they did not feel in control at all, and “9” meant that they felt totally in control. Time to answer was not restricted. Once the two players had answered both questions, a feedback about how many points each player just earned during this trial was displayed on the screen during 200ms. The next trial started right after.

2.5 Data analysis

Only successful trials were used to build statistical models analyzing JoC and prosocial behaviours. We used R (R Core Team, 2018) and lme4 (Bates, et al., 2015) to perform mixed effects analyses.

Prosocial behaviours were analysed from a particular segment of the dataset. More specifically, we labelled as “prosocial” behaviours the Battle of Sexes situations where the players endorsing a leader role (i.e. because they were able to direct the cursor up to their selected target) chose – during the initial choice phase – then reached – during the joint action phase – the target attributing the highest monetary gain to their partners and the lowest monetary gain to themselves. Conversely, “selfish” behaviours corresponded to the Battle of Sexes situations where the players endorsing a leader role chose, then reached, the target attributing the highest reward

to themselves at the expense of their teammates. Based on this distinction, we ran a mixed-effects logistic regression to explore the impact of the games' presentation order (i.e. cooperation and competition were mixed within the blocks vs. blocks of cooperation first vs. blocks of competition first), of the Individualism score (Singelis, 1992), of the payoff amount (i.e. low gain, intermediate gain, high gain) and of the leader configuration (i.e. equal leadership configuration: both players could direct the cursor up to the target of their choice; asymmetrical leadership configuration: only one player could ultimately direct the cursor to the preferred target while the second player could only contribute to the effort) on the emergence of intentional prosocial behaviours. We entered random intercepts as well as random slopes for the payoff effects and leadership effects that varied within the levels of the players nested in dyads.

To fit JoC data with linear mixed models, which require that residuals are normally distributed, we used a square transformation of the data to reduce its initial negative skewness (i.e. reduction from -0.95 to -0.43) and to approach the Gaussian standards. The first linear mixed model aimed to compare the impact of low- and high- level processes on self-agency and joint agency. Thus, we entered motor noise (i.e. no random deviations, small deviations, large deviations), strategic noise (i.e. no strategic noise, pure coordination game, BoS game), leadership (i.e. leader, follower, equal roles), games' presentation order (i.e. mixed design, cooperation first, competition first) and JoC type (i.e. individual vs. collective) into the model as fixed effects. We analysed the main effects of all these factors as well as of all the double and triple interactions involving the JoC type factor, which was central to our initial hypotheses. As recommended by Barr et al., (2013) we used a design-driven approach to determine the maximal random effect structure associated with confirmatory analysis of our fixed effects of interest. Thus, we added random intercepts and random slopes for the effects of JoC type, motor noise, strategic noise and leadership that varied within the levels of the players nested in dyads.

In addition, we ran a second linear mixed model on a restricted part of the dataset corresponding to the BoS configurations where the players endorsed the dominant leader role. Thus, we could analyse the impact of the intentional prosocial behaviours adopted by the leading agent on both individual and collective JoC. To do so, we entered the main effect of strategy (prosocial vs. selfish) and the double interaction between strategy and JoC type as fixed effects. We added random

intercepts and random slopes for the effects of JoC type and strategy that varied within the levels of the players nested in dyads.

For both linear mixed models, degrees of freedom and p-values were approximated from the calculated likelihood ratio tests by using the Satterthwaite's method (see Kuznetsova, Brockhoff, & Christensen, 2016). We used the Tukey HSD method for post-hoc analysis.

3. RESULTS

3.1 JoC models

Judgments of individual or collective control (JoC) were collected using two identical 9-point scales (see Methods). We ran a linear mixed model to estimate the impact of low- and high- level processes on both control judgements (see the data analysis section for additional details).

There was no main effect of the games' presentation order ($F(2, 56) = 1.14$, $p = 0.33$) and no main effect of the question type – individual vs. collective control ($F(1, 103) = 0.14$, $p = 0.71$), on JoC ratings. However, we found that both measures were significantly modulated by the motor noise factor ($F(2, 43) = 46.52$, $p < 0.0001$), JoC ratings being significantly reduced in the case of high motor noise relative to no-motor noise ($t(146.1) = -4.90$, $p < 0.0001$, $b = -7.03$) and to low motor noise, ($t(156) = -3.38$, $p = 0.0009$, $b = -4.36$). Low motor noise conditions also reduced significantly SoA ratings relative to no-motor noise conditions ($t(97.98) = -2.089$, $p = 0.039$, $b = -3.79$).

Concerning the strategic noise, we found that this factor significantly impacted both JoC ratings ($F(2, 39) = 17.11$, $p < 0.0001$), with a significant decrease in the Battle of Sexes setting (i.e. high strategic noise) compared to the situation with no strategic noise, where there was only one target of interest ($t(55.87) = -3.36$, $p = 0.0014$, $b = -4.64$), and to the pure coordination game where there were 2 identical targets of interest ($t(53.33) = -2.04$, $p = 0.046$, $b = -2.88$). JoC ratings were not significantly different in the no- and low strategic noise conditions ($t(139) = 0.32$, $p = 0.75$, $b = 0.37$).

The main effect of leadership ($F(2, 73) = 21.49$, $p < 0.0001$) revealed that both JoC measures were significantly reduced when players endorsed the follower

role, relative to the dominant leader role ($t(148.40) = 7.61, p < 0.0001, b = 8.86$) and relative to configurations where both players had equal leadership ($t(138.20) = 4.79, p < 0.0001, b = 5.37$). However, there was no statistical differences between dominant leadership and equal leadership on JoC ratings ($t(1108) = 0.657, p = 0.51, b = 0.91$).

None of the double interactions was significant but we observed a significant triple interaction between the agency type (individual vs. collective control), the motor noise and the strategic noise ($F(8, 40909) = 5.07, p < 0.0001$), as represented in figure 5. More specifically, we observed that the impact of strategic noise on individual JoC was considerably reduced in the case of high motor noise, with a non-significant difference between intermediate and high strategic noise ($t(61.71) = 1.42, p = 0.16, b = 1.40$) and between high and no strategic noise ($t(17.83) = -0.56, p = 0.58, b = -1.20$). Conversely, the impact of strategic noise on collective JoC was significant even at a high motor noise level, with significantly reduced ratings in the Battle of sexes configuration relative to the intermediate level of strategic noise ($t(61.98) = -3.79, p = 0.00035, b = -3.70$) and to the no strategic noise level ($t(18.30) = -3.125, p = 0.0058, b = -5.75$). This interaction emphasizes the importance of the motor level of intentions in self-agency judgments, compared to the proximal or distal levels of intentions operationalized through the strategic noise factor. In contrast, the latter levels of intentions appeared to have a greater impact on joint agency judgments than the level of motor intentions. We further illustrated this interaction in the figure 5.B., representing the individual slopes (betas) between the high and no noise conditions for both motor and strategic components of the joint action, in both JoC measures.

Fig. 5., Representation of the triple interaction involving the motor noise, the strategic noise and the type of judgment of control (JoC). **A.**, Mean ratings ($\pm$ SEM) of both individual and collective JoC regarding strategic noise (i.e. 1 target = no noise; 2 targets = low noise; BoS = high noise) and motor noise. The impact of strategic noise is not significant on individual JoC when the motor noise is high. On the contrary, the impact of strategic noise on collective JoC is still significant when the motor noise is high. **B.**, Violin plots of the individual estimates ($n = 40$), resulting from the linear mixed model, comparing the high to the no noise condition at both motor and decision levels, and for both types of JoC. In line with the mean ratings, this crossover interaction indicates that the motor level has a higher negative weight than the strategic level on individual agency. Conversely, the strategic level has a higher negative weight than the motor level on collective agency.

Moreover, the triple interaction involving the type of JoC, the strategic noise and the leadership configuration was found to be significant ($F(4, 41125) = 8.75$, $p < 0.0001$) as shown in figure 6. More specifically, we observed that when the agents

549 endorsed the dominant leader role, the difference between the low strategic noise
 550 (i.e. 2 targets with similar interests across both players) and the high strategic noise
 551 conditions (i.e. 2 targets with divergent interests between players) was not significant
 552 in individual JoC ($t(71.46) = 1.29$, $p = 0.20$, $b = 1.321$) while it was significant in
 553 collective JoC ($t(71.46) = 4.23$, $p < 0.0001$, $b = 4.32$). This reduction of the collective
 554 JoC in the BoS configuration highlights the importance of co-representing the co-
 555 agents' distal intentions – which were generally frustrated when these co-agents
 556 endorsed a follower role in the BoS configuration – when it comes to judging
 557 collective agency. Conversely, this pattern of results depicts that only the agents'
 558 own distal intentions are crucial for individual agency ratings.

560 **Fig. 6., Representation of the triple interaction involving the leadership, the strategic**
 561 **noise and the type of judgment of control (JoC).** A., Mean ratings (±SEM) of both
 562 individual and collective JoC regarding strategic noise and leadership configuration. When
 563 the agent endorsed the dominant leader role, increasing strategic noise (2 targets => BoS)
 564 does not significantly reduce individual JoC. In contrast, increasing strategic noise has a

significant influence on collective JoC when the agent endorsed the dominant leader role. In other words, when the agent has the dominant role, the divergence of interests (i.e. in the BoS condition) does not reduce the sense of individual agency but does reduce the sense of collective agency. **B.**, Violin plots of the individual estimates ($n = 98$), resulting from the linear mixed model, depicting the steepness of leadership effects/slopes as a function of the strategic noise and JoC type. The greater the steepness of the slope, the greater the impact of being a leader on JoC. The plot shows that individual JoC is most enhanced when the player is leading in a situation with divergent interests (BoS). In contrast, leadership is associated with a moderate boost in collective JoC, presumably because leadership means unbalanced contribution between the players, thereby reducing their sense of having acted as a team.

We ran a second linear mixed model on a restricted part of the dataset (see the data analysis section) in order to compare the influence of intentional prosocial (or selfish) strategies in individual and in collective JoC. We found no main effect of the planned strategy on both individual and collective JoC ($F(1, 45.23) = 1.30$, $p = 0.26$, $b = -1.08$) but a significant interaction between the planned strategy and the JoC type ($F(2, 137.026) = 6.28$, $p = 0.0025$) as presented in figure 7. More precisely, we observed a significant enhancement of collective JoC in case of prosocial strategies relative to selfish ones ($t(43.14) = 2.077$, $p = 0.0438$, $b = 2.01$). In contrast, there was no statistical difference between selfish and prosocial strategies in individual JoC ($t(35.66) = -0.91$, $p = 0.37$, $b = -0.78$).

Fig. 7., Representation of the double interaction involving the planned strategy and the type of judgment of control (JoC). **A.**, Mean ratings ($\pm$ SEM) of both individual and collective JoC regarding the strategy chosen by the leading player. **B.**, Violin plots of the individual estimates ($n = 98$), resulting from the linear mixed model, depicting the steepness of strategy effects/slopes as a function of the JoC type. The plot shows that the leading players report enhanced collective JoC when they performed intentional prosocial actions relative to selfish ones. In contrast, the prosocial/selfish nature of the strategy does not significantly impact individual JoC.

3.2 Performances & strategies

3.2.1 Performances, gains & strategies links

Teams' performances to the joint task were globally close to ceiling (Mean = 92.35%, SD = 7.17). We further analysed the potential relationships between the dyad's overall success and gains and the prosociality of each player's actions during the task. To do so, we calculated an index of "altruism" (see the data analysis section) for each dyad during BoS games. This index could vary between -1 (i.e. the leading player systematically chose and reached selfish targets) and +1 (i.e. the leading

player systematically chose and reached altruistic targets). Thus, an index of altruism equal to 0 would mean that the participant performed the exact same number of prosocial and selfish actions during the game. Interestingly, we observed a significant positive, yet moderate, correlation (Spearman's $r_s(47) = 0.36$, $p = 0.011$, $r_s^2 = 0.13$) between the altruism's index of the team and the global performance rate, meaning that the more the players exhibited prosocial actions, the more they succeeded to the joint task. Concomitantly, we also observed a significant positive correlation (Spearman's $r_s(47) = 0.35$, $p = 0.013$, $r_s^2 = 0.12$) between the altruism's index and the dyad's mean gains per trial: the more the players exhibited prosocial actions during the game, the higher the dyad's monetary profits at the end. Both correlations are presented in figure 3. Even if the selfish strategy was the most appealing one because it immediately provided higher individual monetary rewards, it yet appeared that in a collaborative motor task, where the final outcomes depend on agents' cooperation, selfish strategies were linked to lower performance and subsequently to lower teams gains overall.

Fig.3. Scatter plots (n = 49 teams) A., Linear correlation between the teams' mean altruism index and the teams' mean success B., Linear correlation between the teams' mean altruism index and the teams' mean gains per trial.

3.2.2 Prosocial vs. selfish strategies

We further analysed which experimental parameters could influence the proportion of participants' intentional altruistic behaviours. To do so, we ran a logistic mixed model to fit the binomial distribution of participants' social strategies (i.e. prosocial vs. selfish). The main effects plus the double and triple interactions of the four following

factors were entered into the model as fixed effects: the games' order, the payoff values (i.e. low = 0.1, medium = 1.2, high = 2.3), the Individualism scores from the abbreviated version of the Singelis scale (Singelis et al., 1995; Triandis & Gelfland, 1998) and the two leadership configurations (i.e. equal leadership: both players could perform altruistic or selfish actions, and "dominant" leadership: only one player could ultimately select the altruistic or selfish target, while the other player could only contribute to the joint effort). The random structure was composed of the random intercepts for the subject and dyad factors plus the random slopes associated with the payoff values and the leadership configuration. We found no main effect of individualism ($\chi^2(1, 98) = 1.43, p = 0.23$), no main effect of the games presentation order ($\chi^2(2, 98) = 1.77, p = 0.41$) and no main effect of payoff values ($\chi^2(3, 98) = 0.25, p = 0.88$) on the proportion of altruistic behaviours. However, we found that the leadership configuration (equal vs. dominant leadership) significantly impacted the proportion of intentional altruistic behaviours ($\chi^2(1, 98) = 5.62, p = 0.018, b = -0.71$). Indeed, participants were less inclined to cede the highest monetary gain to their partners when they endorsed the dominating motor role (27.6% of intentional prosocial behaviours) relative to situations where both players had an equal leadership (35.8% of intentional prosocial behaviours) as shown in figure 4. The enhancement of prosocial behaviours in this latter situation could reflect conflict avoidance in order to ensure a minimal gain to the dyad. None of the double, triple and quadruple interactions was significant.

Fig.4., Impact of leadership asymmetry on planned prosocial behaviours in the Battle of Sexes (n = 98). **A.**, Individual and mean ($\pm$ SEM) proportions of prosocial behaviours depending on the leadership configuration. On average, participants demonstrated more prosocial behaviours in situations of equal leadership relative to situations of dominant leadership. **B.**, Violin plot of the logistic mixed model's individual estimates (slopes) comparing dominant leadership to equal leadership situations. A vast majority of participants showed $\beta < 0$, which explains the significantly reduced number of prosocial behaviours observed in dominant leadership situations.

4. DISCUSSION

In the present study, we aimed to explore the bidirectional link existing between interindividual motor coordination and strategic cooperation in joint action. On the one hand, we investigated how low-level motor and high-level strategic processes interacted in shaping the subjective experience of action, namely sense of agency. On the other hand, we examined how some motor parameters of the task could interfere with players' strategies.

Firstly, regarding our explicit measures of agency (JoC), we observed a significant interplay between motor noise, strategic noise and agency type. As expected, we found that motor noise had a higher impact than strategic noise on individual JoC. Conversely, strategic noise had a higher impact than motor noise on collective JoC. This pattern of results highlights the preponderant role of sensorimotor cues and more generally of low-level motor processes in self-agency (see Moore et al., 2012; Le Bars et al., 2020). Moreover, the superior weighting of high-level decision processes on collective agency would reflect the co-representation of the co-agent's intentions in the joint task (see Sebanz et al., 2003; Knoblich & Sebanz, 2008; Pacherie, 2013). Specifically, the reduction of collective JoC in the pure coordination game (2 identical targets), relative to the condition with only one target of interest, indicates that the potential divergent intention of the co-agent was represented at a *proximal level* considering which target to reach (see Pacherie, 2008; Chambon et al., 2017). Additionally, the reduction of collective JoC in the Battle of sexes, relative to the pure coordination game, indicates that the divergent interest of the co-agent was represented at a *distal level*. Thus, we assume that such co-representations of other's divergent intentions would bring additional decisional options, at both proximal and distal levels, decreasing the fluency of the action selection process. Then, joint SoA would be concomitantly diminished due to a higher load on the prospective component of action selection and planning (see Chambon & Haggard, 2012; Haggard & Chambon, 2012). This distinction between proximal and distal levels of co-represented intentions was less evident in individual JoC, especially when the motor noise was high, which demonstrates again the superior contribution of motor processes over strategic processes to self-agency.

Furthermore, we observed a significant interaction between strategic noise, leadership and agency type on JoC ratings, showing that being the dominant leader

particularly increased individual JoC in the BoS situation. In this asymmetric configuration, dominant players could easily reach the selfish target (higher individual gains), at the expense of their teammates' interests (lower individual gains). Self-agency was thus boosted in case of dominant motor control over a joint action resulting in asymmetric gains. Interestingly, this agency boost in BoS games was weaker for joint agency. More precisely, the BoS condition was still associated to a reduced collective JoC relative to the pure coordination game, even when the agents exerted a dominant motor control over the situation. This result is congruent with the idea that joint agency is strongly dependent on the co-representation of the other's distal intentions. However, note that we used explicit measures of feeling of control only. Such measures are more sensitive to experimental confounds like demand effects (see Moore, 2016; Haggard, 2017). Additional studies using implicit measures of agency (e.g., intentional binding) are thus needed to mitigate the influence of such potential confounds.

Secondly, we further analysed players' strategies. We found that dyads' performance and gains were both positively correlated to altruism scores assessing the number of planned prosocial behaviours exhibited by leaders during the BoS games: altruism in leaders was globally linked to higher performance and subsequently to higher dyads' gains. This pattern of results interrogates about the potential utility of altruistic behaviours in coordination situations made of iterative games (see Meier, 2007). In standard BoS games, prosocial behaviours do not constitute a *rational strategy* since they immediately reduce the agent's profit. However, in the present repetitive motor task, intentional prosocial actions during competitive games could mirror a certain propensity in co-agents to align their intentions, so as to avoid deleterious strategic and motor rivalries leading to failed actions and money loss (miscoordination). It is also a way to boost commitment and reduce competitiveness (e.g., Michael et al., 2016). Congruently, we observed an enhancement of joint agency in prosocial behaviours, reflecting the convergence between the leaders' proximal/distal intentions and their representations of the followers' intentions. Moreover, because participants were not aware of the trials' randomization and counterbalancing, we believe that prosocial behaviours were also performed in the optic of reciprocity (Fehr & Gächter, 2000). Notably, games' iteration allowed the players to anticipate the changing in leader roles, facilitating the emergence of prosocial behaviours.

Importantly, we additionally found that the number of planned prosocial strategies was modulated by the leadership configuration in BoS. In particular, we observed that the number of prosocial behaviours was higher in the dominant leadership situation, relative to the configuration where both players had equal leadership. This leadership asymmetry was not immediately explicit in the task and reflected motor control dominance that could only be understood through experience and trials' iteration. Thus, players' planned strategies were effectively influenced by the motor experience of the task (see Kleiman-Weiner et al., 2016). These last results suggest that the motor parameters of a joint action constitute an integrant part of decisional processes by shaping strategic reasoning. Specifically, when agents exerted equivalent motor control over the joint action, the uncertainty regarding motor effort (motor rivalry) and subsequent reward (reaching a target) increased, making prosociality a valuable option.

AUTHOR CONTRIBUTIONS

All authors developed the study concept and designed the task. S. Le Bars and I. Sari collected the data. S. Le Bars wrote the script for the experimental task, analysed and interpreted the data under the supervision of S. Bourgeois-Gironde, E. Pacherie and V. Chambon. All authors worked on the manuscript and approved the final version for submission.

DECLARATION OF CONFLICTING INTERESTS

The authors declare they had no conflicts of interest with respect to the authorship or the publication of this article.

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