Cognition 165 (2017) 53–60

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Original Articles

Drawn together: When motor representations ground joint actions

Francesco della Gatta [a], Francesca Garbarini [b], Marco Rabuffetti [c], Luca Viganò [a], Stephen A. Butterfill [d], Corrado Sinigaglia [a,e,*]

[a] Department of Philosophy, University of Milan, via Festa del Perdono 7, I-20122 Milano, Italy
[b] Department of Psychology, University of Turin, via Po 14, I-10123 Milano, Italy
[c] Department of Biomedical Technology, IRCCS Don Carlo Gnocchi Foundation Milan, Italy
[d] Department of Philosophy, University of Warwick, Coventry, CV4 7AL, UK
[e] Center for the Study of Social Action, University of Milan, Italy

ARTICLE INFO

Article history:
Received 29 June 2016
Revised 14 April 2017
Accepted 24 April 2017

Keywords:
Joint action
Collective goal
Motor representation
Interpersonal coupling

ABSTRACT

What enables individuals to act together? Recent discoveries suggest that a variety of mechanisms are involved. But something fundamental is yet to be investigated. In joint action, agents represent a collective goal, or so it is often assumed. But how, if at all, are collective goals represented in joint action and how do such representations impact performance? To investigate this question we adapted a bimanual paradigm, the circle-line drawing paradigm, to contrast two agents acting in parallel with two agents performing a joint action. Participants were required to draw lines or circles while observing circles or lines being drawn. The findings indicate that interpersonal motor coupling may occur in joint but not parallel action. This suggests that participants in joint actions can represent collective goals motorically.
© 2017 Elsevier B.V. All rights reserved.

1. Introduction

What enables individuals to act together? People walk, play games and draw together. Joint actions such as these are thought to involve a variety of mechanisms (Knoblich, Butterfill, & Sebanz, 2011). For instance, walking together, as well as joint actions involving music or dance, may be achieved in part thanks to entrainment, the process of synchronizing two or more rhythmic behaviours with respect to phase (Nessler & Gilliland, 2009). Entrainment can occur without any intention to coordinate (Varlet, Bucci, Richardson, & Schmidt, 2015) or even despite individuals attempting not to coordinate their actions (Issartel, Marin, & CadopiM 2007; Ulzen et al., 2008).

Nonrhythmic joint actions can be coordinated by representations concerning others' tasks which can modulate performance of one's own task, facilitating or impairing it (Sebanz, Knoblich, & Prinz, 2003, 2005). For instance, which flankers distract a subject can depend not only on her own task but also on her co-actor's task (Atmaca, Sebanz, & Knoblich, 2011). Likewise, how stimuli such as words are processed can also depend on their relevance to a co-actor's task (Baus et al., 2014). Many joint actions have rhythmic and nonrhythmic aspects; coordination of such actions may involve both entrainment and representations concerning others' tasks (van der Wel & Fu, 2015).

While these mechanisms are plausibly critical for enabling individuals to act together, something fundamental is missing from this picture of joint action. In joint action, agents represent not only each individual's tasks but also a collective goal; or so it is often held (Bratman, 2014; Searle, 1990; Vesper, Butterfill, Knoblich, & Sebanz, 2010). A *collective goal* is an outcome to which two or more actions are directed where this is not, or not only, a matter of each action individually being directed to that outcome (Butterfill, 2016). But how, if at all, are collective goals represented in joint action? And, if they are, how do such representations impact performance in joint action? To date little research has directly addressed these questions. The aim of the present paper is to begin filling this gap.

Previous findings indicate that in joint actions such as playing a piano duet, clinking glasses, jumping together and moving an object, agents' motor representations and processes take into account relations between their own actions and others' in preparing and monitoring their actions (Kourtis, Knoblich, Wozniak, & Sebanz, 2014; Loehr et al., 2013; Meyer, van der Wel, & Hunnius, 2013; Tsai, Sebanz, & Knoblich, 2011; Vesper, van der Wel, Knoblich, & Sebanz, 2013). These findings motivated us to conjecture that participants in joint actions can represent collective goals motorically. Because representing a collective goal (or any goal) triggers motor processes concerning actions that should bring the

* Corresponding author at: Department of Philosophy, University of Milan, via Festa del Perdono 7, I-20122 Milano, Italy.
E-mail address: corrado.sinigaglia@unimi.it (C. Sinigaglia).

http://dx.doi.org/10.1016/j.cognition.2017.04.008
0010-0277/© 2017 Elsevier B.V. All rights reserved.

goal about, representing a collective goal would mean that in each participant there are motor processes concerning not only actions she will perform but also actions another will perform. This could facilitate prediction of, and coordination with, another's actions; but it could also create interference.

One recent challenge in joint action research concerns to what extent agents really do take into account relations between their own actions and others'. In a series of experiments, Dolk et al. (2011), Dolk, Hommel, Prinz, and Liepelt (2013, 2014) have proposed that effects which appear to be specific to joint action are actually merely a consequence of mechanisms for distinguishing one's own actions from other events (see further Dittrich, Bossert, Rothe-Wulf, & Klauer, 2017; Wenke et al., 2011). On this account, what matters are relations between one's own actions and other events rather than between one's own actions and a co-actor's actions. While this alternative account is unlikely to explain the full range of existing findings as it stands (e.g. Baus et al., 2014; Kourtis, Sebanz, & Knoblich, 2013), it would be useful to have a direct approach to testing the conjecture that participants in joint actions can represent collective goals motorically.

Testing this conjecture requires a pair of situations which differ in that one involves a collective goal whereas the other does not. To create such a pair, we need to deviate from prior studies. These typically compare one person acting with two people acting. But to move from one to two agents is not necessarily to move from individual to collective goals. After all, two people creating graffiti in an underpass may merely happen to be drawing alongside each other, so that their actions are parallel but merely individual: this need not involve any collective goal. We therefore seek a pair of minimally different situations which contrast acting in parallel but merely individually with acting jointly.

To create such a pair of situations we adapted a bimanual paradigm, the circle-line drawing paradigm, which has been extensively employed for investigating bimanual interference (Franz, Zelaznik, & McCabe, 1991). When people have to simultaneously perform incongruent movements, such as drawing lines with one hand while drawing circles with the other hand, each movement interferes with the other and line trajectories tend to become ovalized. This "ovalization" has been described as a bimanual coupling effect, suggesting that motor representations for drawing circles can affect motor representations for drawing lines (Garbarini & Pia 2013; Garbarini, Rabuffetti, Piedimonte, Solito, & Berti 2015b; Garbarini et al. 2012, 2013a, 2015a; Piedimonte, Garbarini, Rabuffetti, Pia, & Berti 2014). Importantly, merely observing another drawing a circle while drawing a line oneself does not typically result in ovalization and there are no indicators of interpersonal coupling between mere observers drawing in parallel (Garbarini et al., 2013b, 2016). Our question was therefore what happens when two people are acting together rather than merely in parallel. Would this result in ovalization indicative of interpersonal coupling?

To answer this question we modified the circle-line drawing paradigm. Participants were first asked to act bimanually by continuously drawing lines with the right hand and lines or circles with the left hand. This bimanual task was taken as a baseline measurement in order to rule out subjective differences in bimanual coupling, which could have an influence on the experimental manipulation. Participants were then asked to act unimanually by drawing either circles or lines with their right hands while observing either lines or circles being unimanually drawn by an experimenter playing the role of a confederate (Garbarini et al., 2013b, 2016). We contrasted a Parallel Action condition with a Joint Action condition. These conditions differed only in the instructions given. In the Joint Action condition participants were instructed to perform the task together with the confederate, as if their two drawing hands gave shape to a single design. In the Parallel Action condition, participants were given no such instruction so that they could draw in parallel, observing each other but not acting together. If participants were to follow our instructions, their actions would have the collective goal of drawing a circle and a line in the Joint Action condition but not in the Parallel Action condition. If the collective goal were represented motorically in the Joint Action condition, then, from the point of view of each participant's motor system, it would be almost as if she were representing the whole action bimanually. Accordingly, we predicted that there should be an interpersonal motor coupling effect. This would result in greater ovalization of the lines drawn in the Joint Action condition than in the Parallel Action condition.

Although producing designs involving simple circle and line drawings may appear far from the sorts of joint action that matter in everyday life, the paradigm we shall use is nothing but a simplified version of what artists are doing when they unite to create joint works. And this is but one example of the myriad, and mostly more mundane ways in which performing joint actions enables us to create and do things none of us could achieve alone. In testing the hypothesis that participants in joint actions can represent collective goals motorically, we aim to understand something about what makes joint action possible.

2. Method

2.1. Participants

Thirty-six healthy graduate and undergraduate volunteer students from the University of Milan took part in the experiment (16 males and 20 females; mean age ± sd: 25 ± 3 years; mean educational level: 15 years). All participants were naïve to the purpose of the study and screened to exclude a family history of psychiatric, neurological or medical disease. All of them gave informed consent before the experiment in accordance with the ethical standards of the 1964 Declaration of Helsinki.

2.2. Experimental design

All participants (36) first completed a bimanual baseline experiment. In this experiment, participants individually took part in a version of the standard bimanual circle-line drawing paradigm (Franz et al., 1991) with the following two tasks:

1. Congruent bimanual lines-lines (B-LL): participants were asked to simultaneously draw lines with both hands.
2. Incongruent bimanual circles-lines (B-CL): participants were asked to simultaneously draw lines with the right hand and circles with the left hand.

In both tasks, participants drew on two digitizer tablets, one for each hand, while observing a cross presented on the computer screen (Fig. 1A). The experimenter specified online what they had to draw, either lines with both hands (B-LL task) or circles with the left hand and lines with the right hand (B-CL task). The drawing tasks were presented in a random order. Participants completed twenty trials (10 for each task) with 4 s of rest between each trial; this took around 6 min in total.

For the unimanual main experiment, all female (20) and male subjects (16) were randomly assigned to one of two experimental conditions, either the Parallel Action condition or the Joint Action condition (18 participants for each group, 8 males and 10 females). In both conditions, participants performed four unimanual drawing tasks with a confederate (who was one of the experimenters):

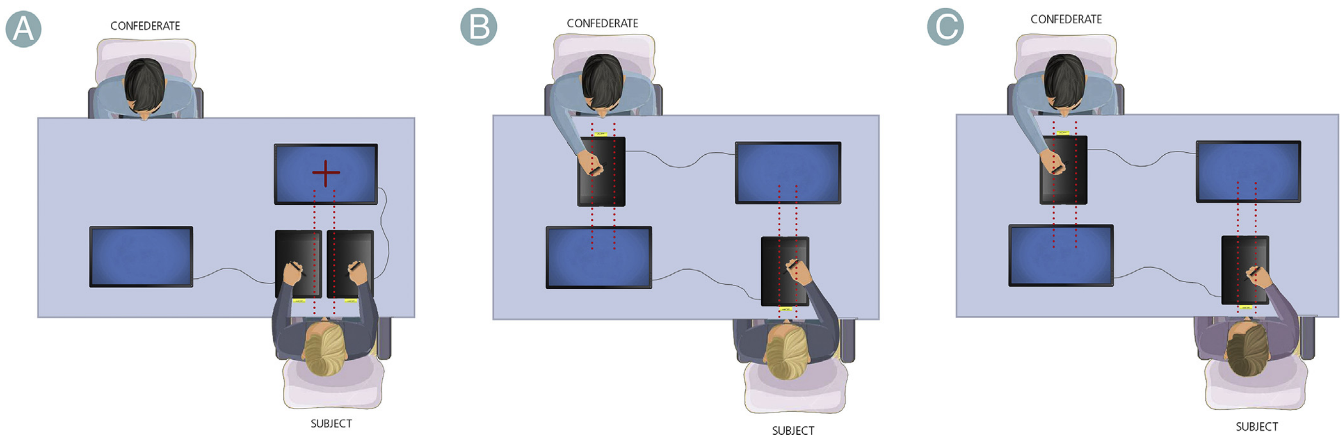

Fig. 1. Experimental setting. Schematic view of the Bimanual Baseline (A), Parallel Action (B) and Joint Action Conditions (C).

1. Congruent Observation Lines: drawing lines while observing lines (O-LL).
2. Congruent Observation Circles: drawing circles while observing circles (O-CC).
3. Incongruent Observation Lines: drawing lines while observing circles (O-CL).
4. Incongruent Observation Circles: drawing circles while observing lines (O-LC).

In both Parallel Action and Joint Action conditions, participants drew circles or lines with their right hands while observing on the screen the circles or lines that were simultaneously drawn by the confederate. The drawing tasks (O-CC; O-LL; O-LC; O-CL) were presented in a random order. Participants completed forty trials (10 for each condition) with 4 s of rest between each trial; this took around 12 min in total. Irrespective of the condition, subjects always performed the same four tasks. The only difference between the Parallel Action and Joint Action conditions concerned the instructions given in advance.

In the Parallel Action condition, participants were instructed: "Look at the screen in front of you. You will see either circles or lines drawn by the confederate sitting across from you. Look at them while drawing either a circle or a line. While drawing, please do not lift the pen from the tablet and try to take advantage of the whole drawing area." [Italian: "Guarda attentamente lo schermo di fronte a te. Vedrai apparire dei cerchi o delle righe disegnate dallo sperimentatore. Osservali mentre disegni a tua volta dei cerchi o delle righe. Per favore, non alzare mai la penna dal tablet e cerca di sfruttare tutta l'area disegnabile."] In the Joint Action condition, participants were instructed: "You and Gabriele [name of confederate] are old friends who have the collective goal of drawing lines and circles together in order to produce a single design. Look at the screen in front of you. You will see either circles or lines drawn by Gabriele. Look at them while drawing either a circle or a line together with him. While drawing, please do not lift your pens from the tablet and try to take advantage of the whole drawing area." [Italian: "Tu e Gabriele siete due vecchi amici e avete come obiettivo comune di disegnare insieme cerchi e linee in modo da creare un unico disegno. Guarda attentamente lo schermo di fronte a te. Al centro appariranno i cerchi o le righe disegnate da Gabriele. Quello che dovrai fare è disegnare insieme con lui cerchi o righe, rispettivamente. Per favore, non alzate mai la penna dal tablet e cercate di sfruttare tutta l'area disegnabile."]

2.3. Experimental setup and procedure

The experimental setup is shown in Fig. 1. Participants sat at a table on a comfortable chair in front of a computer screen with a resolution of 1280 × 1024 pixels, at a distance of 45 cm. They drew circles and lines on Wacom Bamboo Pen Graphics digitizer tablets (30 cm × 20 cm) using a magnetic pen that did not leave a visible trace. In the main, unimanual experimental conditions, a screen displaying the confederate's drawing was positioned on the opposite side of the table in front of the participant and a confederate sat at the table diagonally across from the participant with another PC computer and another digitizer tablet (Fig. 1B and C). The two digitizer tablets and computer screens were controlled by purpose written software. This software, written in Visual Basic (Microsoft, USA), presents a white screen on which the pen contact leaves a blue trace. The software writes a text file containing a sequence of X and Y coordinates and times, thereby recording the pen tip's trajectory. Pen strokes confined to the upper or lower part of the tablet are dropped and ovalization is computed exclusively on strokes which cover the most part of the tablet surface.

The tablets were calibrated at the start of each testing session. A general instruction sheet was read aloud by the participant and they were given a chance to ask any questions before signing an informed consent form. The experimenter then showed the instructions for the task that the participant was to perform and instructed them to maintain a comfort-mode position within and across trials. Once the participant had indicated that they understood the task, they performed a pre-training task phase (60 s) in which they were familiarized with the task. They then completed the bimanual baseline experiment and the unimanual main experiment. At the end of the experiment, each participant was informally debriefed in order to determine (1) if they noticed whether their movements were influenced by the visual stimulus and (2) if they guessed the purpose of the study. None of the participants guessed the purpose of the study. Nevertheless, 18 of 36 participants reported that their movements were somehow influenced by the visual stimulus. They all indicated that this was not intentional. There was no difference between the Joint Action and Parallel Action conditions in the number of participants who reported an influence on their movements (8 and 10 subjects, respectively). Interestingly, one of the participants, who had been in the Parallel Action condition, reported trying to resist the influence of the visual stimulus: "Although I did not want to follow the rhythm of the stimulus observed, I found myself unwittingly going at the same tempo as my partner".

2.4. Scoring

An Ovalization Index (OI) was calculated, following previous studies (see Garbarini et al., 2012, 2013b, 2015b; Piedimonte et al., 2014), as the standard deviation of the pen tip trajectories drawn by the right hand from an absolute vertical axis. (For a thorough description of the steps involved in calculating the OI refer to Garbarini et al., 2012). The OI index ranges between a value of zero for straight trajectories without any sign of ovalization and a value of 100 for circular trajectories.

The average drawing frequency was quantified for each trial as the number of drawing cycles per second (measured in Hz). For the bimanual baseline experiment, the Synchronization Index (SI) was calculated, for each trial, as the absolute difference between the frequency value of line/circle drawing performed by the subject's left hand and the frequency value of line drawing performed by the subject's right hand. For the unimanual main experiment, the SI was calculated, for each trial, as the absolute difference between the frequency value of line/circle drawing trial by the confederate and the frequency value of line/circle drawing performed by the subject's right hand. Furthermore, for each participant, the obtained SI values were averaged across repeated trials and used as dependent variable. Thus, concerning the SI index, a zero value indicates full synchronization, and larger values indicate less synchronization. Finally, in order to assess movement fluency, the average number of speed inversions per single drawing stroke (NIV) was computed (Marquardt & Mai, 1994; Tucha, Tucha, & Lange, 2008). Perfectly fluent movements with a bell-shaped speed profile are characterised by NIV = 1. A NIV value between 1 and 2 indicates intermittently occurring speed inversions, and a NIV larger than 2 indicates constantly occurring speed inversions.

3. Results

3.1. Ovalization Index

3.1.1. Bimanual baseline experiment

In the bimanual baseline experiment, the OI mean values for lines drawn with the right hand were entered in a $2 * 2$ ANOVA, with one between-subject factor (Condition, two levels: "Joint"; "Parallel") and one within-subject factor (Task, two levels: "Incongruent"; "Congruent"). As residuals in the incongruent task (B-CL) were not normally distributed (Shapiro-Wilk $p = 0.00450$), we adopted two separate nonparametric analyses for the congruent (B-LL) and incongruent (B-CL) tasks. First, in order to detect any powerful effect of the between-subject factor, the differences between incongruent (B-CL) and congruent (B-LL) tasks for all subjects were obtained; this difference was used as the dependent variable and the values entered in a Mann-Whitney *U* test. The Mann-Whitney *U* Test showed no significant effect of the between-subject factor Condition (Parallel vs Joint = mean ± sd: 12.35 ± 5.28 vs 13.27 ± 7.11; $Z = -0.031$; $p = 0.975$), meaning that the bimanual coupling effect did not differ between the two conditions. We therefore directly compared the incongruent (B-CL) and congruent (B-LL) values for all subjects using a Wilcoxon signed-rank test for pairwise comparisons with Bonferroni correction for each pairwise comparison (value/number of comparisons: 0.05/2 = 0.025). The Wilcoxon signed-rank test revealed a powerful effect of the within-subject factor Task, showing a significant difference between the incongruent task (B-CL) and the congruent task (B-LL) (mean ± sd = 17.10 ± 6.35 vs 4.29 ± 0.72; $Z = 5.231$; $p < 0.005$; dz = 2.5). The significant OI increase for the right hand drawing lines in the incongruent (B-CL) compared to congruent (B-LL) task is characteristic of bimanual coupling.

3.1.2. Unimanual main experiment

Two separate analyses were performed, one for the circle-drawing tasks (O-CC and O-LC) and one for the line-drawing tasks (O-LL and O-CL). In each analysis, the OI mean values were entered into a $2 * 2$ ANOVA, with one between-subject factor (Condition, two levels: Joint; Parallel) and one within-subject factor (Task, two levels: Incongruent; Congruent).

For the circle-drawing tasks, residual errors in both incongruent (O-LC) and congruent (O-LL) tasks were normally distributed (Shapiro-Wilk $p = 0.09069$ and $p = 0.14675$). The ANOVA showed no significant effects: the between-subject factor Condition ($F(1,34) = 0.543$; $p = 0.466$), the within-subject factor Task ($F(1,34) = 0.279$; $p = 0.601$), and the interaction of these ($F(1,34) = 0.055$; $p = 0.815$) were all nonsignificant.

For the line-drawing tasks, residual errors in both incongruent (O-CL) and congruent (O-LL) tasks were not normally distributed (Shapiro-Wilk $p = 0.01219$ and $p = 0.00336$). We therefore adopted nonparametric analyses. In order to detect any powerful effect in the between-subject factor, the differences between incongruent (O-CL) and congruent (O-LL) tasks for all subjects were obtained; this difference was used as the dependent variable and the values entered in a Mann-Whitney *U* test. The Mann-Whitney *U* Test showed a significant effect of the between-subject factor Condition (Parallel vs Joint = mean ± sd: 0.03 ± 0.19 vs 0.45 ± 0.29; $Z = -4.113$; $p < 0.0005$). In the Joint Action condition, Wilcoxon matched-pairs tests with Bonferroni correction revealed a significant OI increase for the right hand drawing lines in the incongruent (O-CL) compared to the congruent (O-LL) task (mean ± sd = 4.57 ± 1.09 vs 4.12 ± 0.96; $Z = 3.680$; $p < 0.0005$; dz = 1.08). By contrast, in the Parallel Action condition, no significant difference was found between incongruent (O-CL) and congruent (O-LL) tasks (mean ± sd = 3.96 ± 0.64 vs 3.94 ± 0.66; $Z = 0.566$; $p = 0.571$). This indicates that, for the right hand drawing lines, OI was larger in the incongruent (O-CL) compared to congruent (O-LL) task in the Joint Action condition only (see Fig. 2A).

Finally, the variances of the OI values obtained from line-drawing tasks and circle-drawing tasks were compared by means of an F test. This showed significantly greater variance in circle drawings than in line drawings for both Congruent and Incongruent tasks (Congruent comparison: Lines-Lines Var = 0.66 vs Circles-Circles Var = 55.37; $p < 0.001$; Incongruent comparison: Lines-Circles Var = 0.87 vs Circles-Lines Var = 61.87; $p < 0.001$).

3.2. Synchronization index

In both the bimanual baseline experiment and the unimanual main experiment, the SI value was entered in an ANOVA, with one between-subject factor (Condition, two levels: "Joint"; "Parallel") and one within-subject factor (Task, two levels: "Incongruent"; "Congruent"). Post hoc comparisons were performed by using Duncan's test.

3.2.1. Bimanual baseline experiment

In the bimanual baseline experiment, for both congruent (B-LL) and incongruent (B-CL) tasks, residuals were not normally distributed (Shapiro-Wilk $p = 0.00000$ and $p = 0.00022$). We therefore adopted two separate nonparametric analyses. In order to detect any powerful effect of the between-subject factor Condition (Parallel vs Joint), the differences between incongruent (B-CL) and congruent (B-LL) values for all subjects were obtained; this difference was used as the dependent variable and entered in a Mann-Whitney *U*-Test. The Mann-Whitney *U*-Test showed no significant effect of the between-subject factor Condition (Parallel vs Joint = mean ± sd: 0.07 ± 0.07 vs 0.09 ± 0.09; $Z = -0.648$; $p = 0.517$.

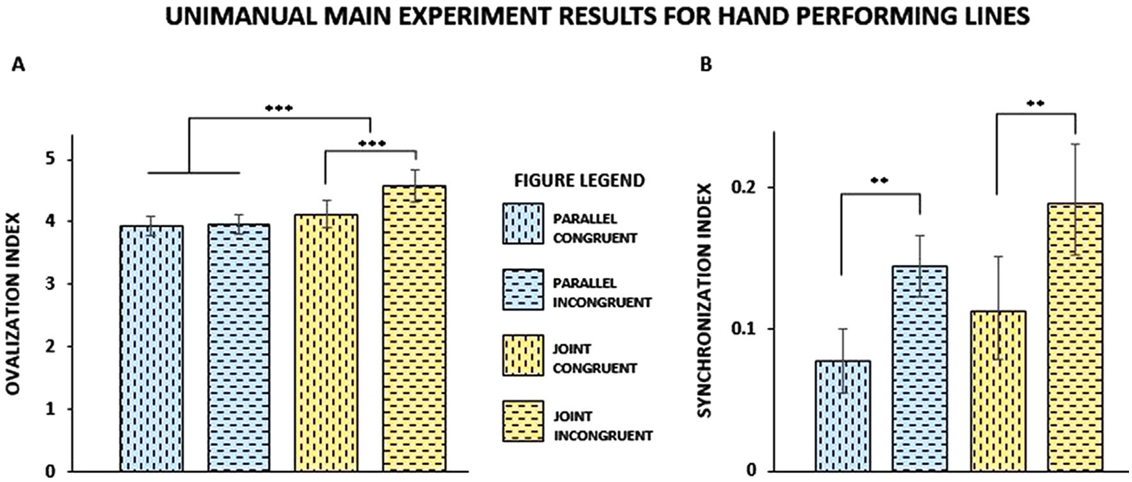

Fig. 2. Unimanual main experiment results of all subjects for the right hand performing lines. Error bars indicate s.e.m. Asterisks indicate significance difference (** $p < 0.005$; *** $p < 0.0005$). In A, all subject's Ovalization Index (OI) mean values are plotted: a significant OI increase was found only for the Joint Action condition in the incongruent condition. In B, all subject's Synchronization Index (SI) mean values are plotted: no difference between conditions was found; for all participants SI was larger in the incongruent (O-CL) compared to the congruent (O-LL) tasks.

We therefore directly compared the values from incongruent (B-CL) and congruent (B-LL) tasks for all subjects using a Wilcoxon signed-rank test for pairwise comparisons in order to detect any powerful effect of the within-subject factor. Bonferroni correction was applied for both pairwise comparisons (with value/number of comparisons: 0.05/2 = 0.025). Wilcoxon matched pairs tests, after Bonferroni correction, revealed a powerful effect of the within-subject factor Task, showing a significant difference between the incongruent (B-CL) and the congruent (B-LL) task (mean ± sd = 0.08 ± 0.08 vs 0.04 ± 0.06; $Z = 2.584$; $p = 0.009$). For all participants, SI was larger in the incongruent (B-CL) than in the congruent (B-LL) task. This indicates that, in the bimanual baseline experiment, the participants assigned to the two Conditions (Joint vs Parallel) did not differ from each other in terms of synchronization.

3.2.2. Unimanual main experiment

In the unimanual main experiment, for the line drawing tasks, residual errors were not normally distributed in either the incongruent (O-CL) or the congruent (O-LL) task (Shapiro-Wilk $p = 0.00284$ and $p = 0.0001$). We therefore adopted two separate nonparametric analyses. In order to detect any powerful effect of the between-subject factor Condition (Parallel vs Joint), the differences between incongruent (O-CL) and congruent (O-LL) values for all subjects were obtained; this difference was used as the dependent variable and entered in a Mann-Whitney *U*-Test. The Mann-Whitney *U*-Test showed no significant effect of the between-subject factor Condition (Parallel vs Joint = mean ± sd: 0.07 ± 0.12 vs 0.07 ± 0.09; $Z = 0.126$; $p = 0.9$). We therefore directly compared the values from incongruent (O-CL) and congruent (O-LL) tasks for all subjects using a Wilcoxon signed-rank test for pairwise comparisons in order to detect any powerful effect of the within-subject factor Task. Bonferroni correction was applied for both pairwise comparisons (with value/number of comparisons: 0.05/2 = 0.025). Wilcoxon matched pairs tests, after Bonferroni correction, revealed a powerful effect of the within-subject factor Task, showing a significant difference between the incongruent (O-CL) and the congruent (O-LL) task (mean ± sd = 0.17 ± 0.13 vs 0.09 ± 0.12; $Z = 3.425$; $p < 0.005$). For all participants, SI was larger in the incongruent (O-CL) than in the congruent (O-LL) task. This indicates that, in the unimanual main experiment, the participants assigned to the two Conditions (Joint vs Parallel) did not differ from each other in terms of synchronization (see Fig. 2B).

For the circle drawing tasks, residual errors were not normally distributed in either the incongruent (O-LC) or the congruent (O-LL) task (Shapiro-Wilk $p = 0.01642$ and $p = 0.00011$). We therefore adopted two separate nonparametric analyses. In order to detect any powerful effect of the between-subject factor Condition (Parallel vs Joint), the differences between incongruent (O-LC) and congruent (O-LL) values for all subjects were obtained; this difference was used as the dependent variable and entered in a Mann-Whitney *U*-Test. The Mann-Whitney *U*-Test showed no significant effect of the between-subject factor Condition (Parallel vs Joint = mean ± sd: 0.05 ± 0.09 vs 0.01 ± 0.06; $Z = -1.55$; $p = 0.126$). We therefore directly compared the values from incongruent (O-LC) and congruent (O-LL) tasks for all subjects using a Wilcoxon signed-rank test for pairwise comparisons in order to detect any powerful effect of the within-subject factor Task. Bonferroni correction was applied for both pairwise comparisons (with value/number of comparisons: 0.05/2 = 0.025). Wilcoxon matched pairs tests, after Bonferroni correction, revealed no powerful effect of the within-subject factor Task, showing no significant difference between the incongruent (O-LC) and the congruent (O-LL) task (mean ± sd = 0.15 ± 0.14 vs 0.18 ± 0.15; $Z = 1.657$; $p = 0.097$). This indicates that, for all participants, SI was equal in the incongruent (O-LC) and in the congruent (O-LL) tasks, and that the participants assigned to the two Conditions (Joint vs Parallel) did not differ from each other in terms of synchronization.

3.3. Number of inversions (NIV)

Subjects performed the drawing task in a fluent manner (values NIV = 1 were found in 94.1% of all trials) without significant differences across conditions. A Mann-Whitney *U*-Test showed no significant effect between Parallel versus Joint Condition in both unimanual main experiment ($p = 0.447$) and bimanual baseline experiment ($p = 0.112$).

4. Discussion

The aim of the present study was to directly investigate, for the first time, how performing a joint action might differ from performing parallel but merely individual actions with respect to what is represented motorically. Can participants in joint actions represent collective goals motorically? We asked participants to draw lines or circles while observing circles or lines being drawn by a confederate; we manipulated whether each participant conceived of herself as acting jointly with, or in parallel with, the confederate. The visual feedback and the basic action required were the same in both Joint and Parallel Action conditions, and drawing performance was generally fluent (as indicated by NIV scores): only the instructions varied.

The main finding was that lines drawn by participants observing the confederate draw circles were more ovalized by those acting jointly than by those acting in parallel. How can this difference in ovalization be explained? The difference is consistent with previous studies investigating whether and how visual feedback can induce spatial interference during unimanual action. These studies clearly indicate that observing a confederate's hand drawing circles does not affect the trajectory of the observer's own hand when she is drawing lines (Garbarini et al., 2013b, 2016). This would seem to exclude the possibility of explaining the difference between acting jointly and acting in parallel as a consequence merely of imitative or counter-imitative effects (e.g. Brass, Bekkering, Wohlschläger, & Prinz, 2000; Heyes, 2011). Why else might there be a difference between acting jointly and acting in parallel?

When an individual is bimanually drawing lines and circles, the line drawing hand tends to ovalize its trajectories, as in our bimanual baseline experiment. (This experiment also demonstrated that there was no difference between participants assigned to the two conditions, ruling out the possibility of relevant individual differences in susceptibility to ovalization.) The bimanual interference we observed is a highly reproducible effect, and one present across different ages (Piedimonte et al., 2014). It has been interpreted as a motor coupling effect as it is more tightly linked to action representation than to movement execution (Swinnen et al., 2003). The link to action representation is also evident at the neuronal level. Indeed, bimanual coupling has been shown to involve a parieto-frontal network centred on the pre-supplementary motor area (pre-SMA) and the posterior parietal cortex, which is more closely linked to action representation than to movement execution (e.g., Garbarini et al., 2013a; Sadato, Yonekura, Waki, Yamada, & Ishii, 1997; Wenderoth, Debaere, Sunaert, Hecke, & Swinnen, 2004). We suggest that ovalization in the Joint Action condition has fundamentally the same source as ovalization in individual performance of a bimanual action: it is a consequence of representing the goal of drawing both a circle and a line. Our hypothesis is that individuals performing a joint action (unlike those who are merely acting in parallel) can represent the collective goal of their joint action motorically. If so, participants in the Joint Action condition may have represented the collective goal of drawing both a circle and a line even while actually only drawing a line. Representing this goal would trigger motor processes in the participant concerning both circle and line drawing actions, somewhat like those which would occur were the participant performing both drawing actions herself. These motor processes should interfere with each other, somewhat as they do in bimanual action. Of course, in joint action the hands belong to different individuals: this may explain why the interference is stronger in bimanual action than in unimanual joint action. But the critical point for us is that in both cases, bimanual action and joint action, interference is a consequence of representing motorically the goal of drawing both a circle and a line.

Given our hypothesis that collective goals are represented motorically in joint action, why did we find a difference between joint action and parallel action in the line-drawing task but not in the circle-drawing task? No such difference was reported in the previous study of bimanual action (Franz et al., 1991), which found effects on ovalization for both circles and lines. Further, the explanation we have offered implies that collective goals should be represented motorically in both line- and circle-drawing tasks. One possibility is that those performing the circle-drawing task were less likely to represent collective goals than those performing the line-drawing task, perhaps because the circle-drawing task was more taxing (compare Vesper et al., 2013 for a potentially related asymmetry). An alternative possibility is that those performing the circle-drawing task did indeed represent the collective goal motorically but the effects of this representation were masked by the variability involved drawing circles. To examine this possibility, we compared the variance of the OI values obtained from drawings of lines and drawings of circles. There was significantly greater variance in drawings of circles than in drawings of lines. This greater variance, together with the fact that the joint action effect is smaller than the variance observed, may explain the apparent difference between the line-drawing and the circle-drawing tasks. Greater variability in drawing circles may mask the effect of joint action on ovalization. Indeed, other researchers have relied on line drawing rather than circle drawing to detect interference effects for just this reason (e.g. Garbarini et al., 2012, 2013a, 2013b). While the present results do not allow us to decisively distinguish these explanations for the difference between the line- and circle-drawing tasks, the important point for our purposes is this: on either explanation, at least those performing the line-drawing task represented collective goals motorically.

One might wonder whether a simpler explanation of the difference in ovalization between acting jointly and acting in parallel might be given by appeal to attention. Manipulating whether participants were instructed to act jointly or in parallel may have induced an attentional bias. In performing joint actions, participants may have been biased to attend more to the other's drawing than when acting in parallel. However, although attention could play some role, we regard it as implausible that differences in attention are sufficient to explain the observed differences in ovalization. Why? First, in all conditions of all tasks, the instructions explicitly required participants to focus on the confederate's drawings. Second, if attention fully explained the difference in ovalization, we would expect it also to result in greater synchronization when acting jointly than when acting in parallel. In fact we observed no significant difference in synchronization between acting jointly and acting in parallel. There was even a nonsignificant trend towards less synchronization when acting jointly, counter to what we would expected if attention played a role.

Alternative hypotheses about the difference in ovalization between acting jointly and acting in parallel might somehow invoke entrainment. Such an alternative is initially attractive because our task, unlike some others (e.g. Jung, Holländer, Müller, & Prinz, 2011), involved rhythmic movements. One might suppose that stronger entrainment would indicate closer coupling between participant and confederate, and that this coupling might somehow result in greater ovalization. But there is a clear obstacle to offering any such explanation of our findings: as already noted, participants were no less synchronized with the confederate when acting in parallel than when acting jointly. This indicates that if there was any difference with respect to entrainment, there was more entrainment in the parallel condition than in the joint action condition. So to explain our findings by invoking entrainment, it would be necessary to discover a theoretical link between lesser entrainment and greater ovalization.

A related challenge would face an attempt to explain the difference in ovalization between acting jointly and acting in parallel by appeal to temporal adaptation, a mechanism whereby individuals speed up or slow down their actions to match observed actions (Keller, 2008; Konvalinka, Vuust, Roepstorff, & Frith, 2010). It has recently been suggested that coordination effects which were held to be a consequence of how actions are represented motorically are in fact due merely to temporal adaptation (e.g. Lelonkiewicz

& Gambi, 2016). Could our findings similarly be explained merely by temporal adaptation and so not support the hypothesis that collective goals can be represented motorically? To show that they could it would be necessary, first, to link temporal adaptation to ovalization; and, second, to link the lower temporal adaptation observed in performing joint actions with greater ovalization.

While our aim was not to investigate entrainment or temporal adaptation, the observation that actions are no less synchronized when acting in parallel than when performing a joint action suggests that the extent to which actions are entrained, and the extent to which temporal adaptation occurs, can be dissociated from the extent to which motor representations of collective goals influence actions (compare van der Wel & Fu, 2015). This is a topic for further investigation.

A higher-level alternative to our hypothesis about motor representations of collective goals might involve task co-representation, which has been invoked to explain how people coordinate joint actions (e.g. Baus et al., 2014; Sebanz, Bekkering, & Knoblich, 2006). As it is typically understood, task co-representation would involve participants representing the confederate's task in addition to representing their own task. Although this may occur in our experiment, the existing literature suggests that task co-representation can occur when agents are merely acting in parallel (e.g. Atmaca et al., 2011; Böckler et al., 2012). If we think that ovalization can be explained by invoking task co-representation, we would therefore need some way of explaining why task co-representation is less likely to occur in when acting in parallel than when performing joint actions. An alternative possibility would be to eschew the idea that participants represent the confederate's task in favour of the view that in performing joint actions they represent the larger task of drawing circles and lines (compare Vesper, Knoblich, Sebanz, 2014). On this view, participants performing a joint action would have a task representation specifying a collective goal. But how could that task representation affect the drawing actions? One possibility is that it does so by triggering a motor representation of the collective goal. When understood in this way, appeal to task co-representation is an elaboration of, rather than a competitor to, our hypothesis that collective goals can be represented motorically.

Effects associated by some with task co-representation have been interpreted as due to non-social attentional mechanisms (e.g. Dolk, Hommel, Prinz, & Liepelt, 2014). Could such interpretation be extended to cover findings such as ours? On such an interpretation, the greater ovalization effects we observed in joint action would be due to the greater salience of the confederate's drawing together with the need to distinguish this event from the self-produced drawing (compare Dolk et al., 2014 p. 1229). Salience may have some effect, of course. But an immediate obstacle to this interpretation is the fact that we compared parallel with joint action (rather than individual with joint action, as in many studies of task co-representation). All other things being equal, a non-social attentional mechanism should be required no less when acting in parallel with others than when acting jointly with them.

A further potential issue is that participants in our experiments were acting on our instructions. We assume that fundamentally the same processes are at work when people act spontaneously, although of course our data do not bear directly on this assumption.

Even if alternatives involving attention, entrainment or temporal adaptation cannot fully explain our findings, there may still seem to be reason to resist our hypothesis. It may seem bizarre to suggest that participants represented actions which no individual performed and which would have required two hands to perform. After all, when performing joint actions, participants were only ever drawing with their right hands. But however bizarre it may seem, it is a natural extension of earlier studies which indicate that effects characteristic of motor coupling, such as an increase in the ovalization of a straight line, can occur even when an individual is actually acting unimanually. Such effects have been observed in hemiplegic patients affected by anosognosia for hemiplegia (Garbarini et al., 2012). Although they did not actually move both hands when asked to draw circles and lines simultaneously, these patients did claim to move their paralyzed hands and their lines were clearly ovalized. Relatedly, amputees with phantom limb experiences were also found to ovalize straight lines (Franz & Ramachandran, 1998), as were patients with hemisomatoagnosia who misidentify other's limbs as their own (Garbarini et al., 2013b). All three cases suggest that the execution of a bimanual action is unnecessary for effects characteristic of motor coupling to occur: it is sufficient that the goal of drawing circles and lines is represented motorically. This has been strongly corroborated by a version of the task involving motor imagery in healthy subjects who were either actually drawing circles and lines with two hands or actually drawing lines with just one hand while merely imagining drawing circles with the other hand (Garbarini et al., 2013a; Piedimonte et al., 2014). The results showed clear ovalization in both conditions, suggesting that effects characteristic of motor coupling can also be a consequence of motor representation and do not require that one individual is actually using both hands. Our study takes the further step from individual to joint action and provides evidence that there can be interpersonal motor coupling.

Others have taken a related step in providing evidence that an individual may take into account relations between her own actions and another's in preparing and monitoring her actions (e.g. Kourtis et al., 2014; Meyer et al., 2013; Tsai et al., 2011; Vesper et al., 2013). For example, Loehr et al. (2013) showed that pianists playing chords together distinguish errors which affect a pianist's own part only from errors which affect the harmony of the chord and so result in failure to achieve a collective goal. Richardson, Marsh, and Baron (2007) showed that acting together with another rather than alone can modulate how an individual grasps an object. And Novembre, Ticini, Schutz-Bosbach, and Keller (2013) showed that momentarily disrupting motor processes by means of double-pulse transcranial magnetic stimulation impairs a pianist's ability to appropriately adjust tempo to match her (recorded) partner's performance independently of impairing other aspects of her performance. Taken together, these findings suggest that an individual may take into account relations between her own actions and another's in preparing, performing and anticipating actions. But does doing so involve representing collective goals? To answer this question a new approach was needed. Earlier studies all compare one individual's performance with multiple individuals' performances. But to isolate indicators that a collective goal is represented, it is necessary to compare multiple individuals acting in parallel with multiple individuals acting jointly (Gilbert, 1990; Searle, 1990). By doing this in the present study we show, for the first time, that participants in joint actions can indeed represent collective goals motorically.

Motor representations of collective goals matter for the coordination of actions. Coordinating a bimanual action often involves representing motorically an outcome to be realised by the movements of two hands. If we are right, coordinating a joint action may sometimes be similar insofar as it involves a motor representation of an outcome to be realised by the movements of two (or more) agents. Of course, not all coordination challenges can be met by invoking motor representations---many joint actions involve collective goals that cannot be represented motorically, goals such as meeting at an airport or celebrating a birthday. But for small scale joint actions involving passing objects, playing chords or drawing together, collective goals represented motorically may be indispensable. And these are the foundations of all joint action.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2017.04.008.

References

Atmaca, S., Sebanz, N., & Knoblich, G. (2011). The joint flanker effect: sharing tasks with real and imagined co-actors. *Experimental Brain Research, 211*, 371–385.

Baus, C., Sebanz, N., Fuente, V. d. l., Branzi, F. M., Martin, C., & Costa, A. (2014). On predicting others' words: Electrophysiological evidence of prediction in speech production. *Cognition, 133*(2), 395–407.

Böckler, A., Knoblich, G., & Sebanz, N. (2012). Effects of a co-actor's focus of attention on task performance. *Journal of Experimental Psychology: Human Perception and Performance, 38*(6), 1404–1415.

Brass, M., Bekkering, H., Wohlschläger, A., & Prinz, W. (2000). Compatibility between observed and executed finger movements: Comparing symbolic, spatial, and imitative cues. *Brain and Cognition, 44*(2), 124–143.

Bratman, M. E. (2014). *Shared agency: A planning theory of acting together*. Oxford: Oxford University Press.

Butterfill, S. A. (2016). Planning for collective agency. In C. Misselhorn (Ed.). *Collective agency and cooperation in natural and artificial systems. Philosophical studies series* (Vol. 122, pp. 149–168). New York: Springer.

Dittrich, K., Bossert, M.-L., Rothe-Wulf, A., & Klauer, K. C. (2017). The joint flanker effect and the joint Simon effect: On the comparability of processes underlying joint compatibility effects. *The Quarterly Journal of Experimental Psychology, 70* (9), 1808–1823.

Dolk, T., Hommel, T., Colzato, L. S., Schütz-Bosbach, S., Prinz, W., & Liepelt, R. (2011). How 'social' is the Social Simon Effect? *Frontiers in Psychology, 2*, 84.

Dolk, T., Hommel, B., Prinz, W., & Liepelt, R. (2013). The (not so) social Simon effect: A referential coding account. *Journal of Experimental Psychology: Human Perception and Performance, 39*(5), 1248–1260.

Dolk, T., Hommel, B., Prinz, W., & Liepelt, R. (2014). The joint flanker effect: Less social than previously thought. *Psychonomic Bulletin & Review, 21*(5), 1224–1230.

Franz, E. A., & Ramachandran, V. S. (1998). Bimanual coupling in amputees with phantom limbs. *Nature Neuroscience, 1*, 443–444.

Franz, E. A., Zelaznik, H. N., & McCabe, G. (1991). Spatial topological constraints in a bimanual task. *Acta Psychologica, 77*, 137–151.

Garbarini, F., D'Agata, F., Piedimonte, A., Sacco, K., Rabuffetti, M., Cauda, F., ... Berti, A. (2013a). Drawing lines while imagining circles: neural basis of the bimanual coupling effect during motor execution and motor imagery. *Neuroimage, 88C*, 100–112.

Garbarini, F., Mastropasqua, A., Sigaudo, M., Rabuffetti, M., Piedimonte, A., Pia, L., & Rocca, P. (2016). Abnormal sense of agency in patients with schizophrenia: Evidence from bimanual coupling paradigm. *Frontiers Behavioral Neuroscience, 10*, 43.

Garbarini, F., & Pia, L. (2013). Bimanual coupling paradigm as an effective tool to investigate productive behaviors in motor and body awareness impairments. *Frontiers in Neuroscience, 7*, 737.

Garbarini, F., Pia, L., Piedimonte, A., Rabuffetti, M., Gindri, P., & Berti, A. (2013b). Embodiment of an alien hand interferes with intact-hand movements. *Current Biology, 23*. 2–r57-R58.

Garbarini, F., Rabuffetti, M., Piedimonte, A., Pia, L., Ferrarin, M., Frassinetti, F., ... Berti, A. (2012). 'Moving' a paralysed hand: bimanual coupling effect in patient with anosognosia for hemiplegia. *Brain, 135*, 1486–1497.

Garbarini, F., Rabuffetti, M., Piedimonte, A., Solito, G., & Berti, A. (2015b). Bimanual coupling effects during arm immobilization and passive movements. *Human Movement Science, 41*, 114–126.

Garbarini, F., Turella, L., Rabuffetti, M., Cantagallo, A., Piedimonte, A., Fainardi, E., ... Fadiga, L. (2015a). Bimanual Non-congruent actions in motor neglect syndrome: a combined behavioral/fMRI study. *Frontiers Human Neuroscience, 9*, 541.

Gilbert, M. P. (1990). Walking together: A paradigmatic social phenomenon. *Midwest Studies in Philosophy, 15*, 1–14.

Heyes, C. (2011). Automatic imitation. *Psychological Bulletin, 137*(3), 463–483.

Issartel, J., Marin, L., & Cadopi, M. (2007). Unintended interpersonal co-ordination: 'Can we march to the beat of our own drum?'. *Neuroscience Letters, 411*, 174–179.

Jung, C., Holländer, A., Müller, K., & Prinz, W. (2011). Sharing a bimanual task between two: Evidence of temporal alignment in interpersonal coordination. *Experimental Brain Research, 211*(3–4), 471–482.

Keller, P. E (2008). Joint action in music performance. In *Enacting intersubjectivity: A cognitive and social perspective to the study of interactions* (pp. 205–221). IOS Press.

Knoblich, G., Butterfill, S., & Sebanz, N. (2011). Psychological research on joint action: Theory and data. In Brian Ross (Ed.). *Psychology of learning and motivation* (Vol. 51). Academic Press.

Konvalinka, I., Vuust, P., Roepstorff, A., & Frith, C. D. (2010). Follow you, follow me: Continuous mutual prediction and adaptation in joint tapping. *The Quarterly Journal of Experimental Psychology, 63*(11), 2220–2230.

Kourtis, D., Knoblich, G., Wozniak, M., & Sebanz, N. (2014). Attention allocation and task representation during joint action planning. *Journal of Cognitive Neuroscience, 26*(10), 2275–2286.

Kourtis, D., Sebanz, N., & Knoblich, G. (2013). Predictive representation of other people's actions in joint action planning: An EEG study. *Social Neuroscience, 8*, 31–42.

Lelonkiewicz, J. R., & Gambi, C. (2016). Spontaneous adaptation explains why people act faster when being imitated. *Psychonomic Bulletin & Review*. http://dx.doi.org/10.3758/s13423-016-1141-3.

Loehr, J. D., Kourtis, D., Vesper, C., Sebanz, N., Knoblich, G., et al. (2013). Monitoring individual and joint action outcomes in duet music performance. *Journal of Cognitive Neuroscience, 25*, 1049–1061.

Marquardt, C., & Mai, N. (1994). A computational procedure for movement analysis in handwriting. *Journal of Neuroscience Methods, 52*, 39–45.

Meyer, M., van der Wel, R. P. R. D., & Hunnius, S. (2013). Higher-order action planning for individual and joint object manipulations. *Experimental Brain Research, 22*, 579–588.

Nessler, J. A., & Gilliland, S. J. (2009). Interpersonal synchronization during side by side treadmill walking is influenced by leg length differential and altered sensory feedback. *Human Movement Science, 28*, 772–785.

Novembre, G., Ticini, L. F., Schutz-Bosbach, S., & Keller, P. E. (2013). Motor simulation and the coordination of self and other in real-time joint action. *Social Cognitive and Affective Neuroscience, 9*, 1062–1068.

Piedimonte, A., Garbarini, F., Rabuffetti, M., Pia, L., & Berti, A. (2014). Executed and imagined bimanual movements: A study across different ages. *Developmental Psychology, 50*, 1073–1080.

Richardson, M. J., Marsh, K. L., & Baron, R. M. (2007). Judging and actualizing intrapersonal and interpersonal affordances. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 845–859.

Sadato, N., Yonekura, Y., Waki, A., Yamada, H., & Ishii, Y. (1997). Role of the supplementary motor area and the right premotor cortex in the coordination of bimanual finger movements. *Journal of Neuroscience, 17*, 9667–9674.

Searle, J. R. (1990). Collective intentions and actions. In P. Cohen, J. Morgan, & M. E. Pollack (Eds.), *Intentions in communication* (pp. 90–105). Cambridge: Cambridge University Press.

Sebanz, N., Bekkering, H., & Knoblich, G. (2006). Joint action: Bodies and mind moving together. *Trends in Cognitive Sciences, 10*(2), 70–76.

Sebanz, N., Knoblich, G., & Prinz, W. (2003). Representing others' actions: Just like one's own? *Cognition, 88*(3), B11–B21.

Sebanz, N., Knoblich, G., & Prinz, W. (2005). How two share a task: Corepresenting stimulus-response mappings. *Journal of Experimental Psychology: Human Perception and Performance, 31*, 1234–1246.

Swinnen, S. P., Puttemans, V., Vangheluwe, S., Wenderoth, N., Levin, O., & Dounskaia, N. (2003). Directional interference during bimanual coordination: is interlimb coupling mediated by afferent or efferent processes? *Behavioral Brain Research, 139*(1–2), 177–195.

Tsai, J. C.-C., Sebanz, N., & Knoblich, G. (2011). The GROOP effect: Groups mimic group actions. *Cognition, 118*, 135–140.

Tucha, O., Tucha, L., & Lange, K. W. (2008). Graphonomics, automaticity and handwriting assessment. *Literacy, 42*, 145–155.

van Ulzen, N. R., Lamoth, C. J., Daffertshofer, A., Semin, G. R., & Beek, P. J. (2008). Characteristics of instructed and uninstructed interpersonal coordination while walking side-by-side. *Neuroscience Letters, 432*, 88–93.

Varlet, M., Bucci, C., Richardson, M. J., & Schmidt, R. C. (2015). Informational constraints on spontaneous visuomotor entrainment. *Human Movement Science, 41*, 265–281.

Vesper, C., Butterfill, S., Knoblich, G., & Sebanz, N. (2010). A minimal architecture for joint action. *Neural Networks, 23*, 998–1003.

Vesper, C., Knoblich, G., & Sebanz, N. (2014). Our actions in my mind: Motor imagery of joint action. *Neuropsychologia, 55*, 115–121.

Vesper, C., van der Wel, R. P. R. D., Knoblich, G., & Sebanz, N. (2013). Are you ready to jump? Predictive mechanisms in interpersonal coordination. *Journal of Experimental Psychology: Human Perception and Performance, 39*(1), 48–61.

van der Wel, R. P. R. D., & Fu, E. (2015). Entrainment and task co-representation effects for discrete and continuous action sequences. *Psychonomic Bulletin & Review, 22*(6), 1–7.

Wenderoth, N., Debaere, F., Sunaert, S., Hecke, P., & Swinnen, S. P. (2004). Parieto-premotor areas mediate directional interference during bimanual movements. *Cerebral Cortex, 14*, 1153–1163.

Wenke, D., Atmaca, S., Holländer, A., Liepelt, R., Baess, P., & Prinz, W. (2011). What is shared in joint action? Issues of co-representation, response conflict, and agent identification. *Review of Philosophy and Psychology, 2*(2), 147–172.