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ABSTRACT

Mutual adaptive timing (MAT), the capacity to adapt one's timing to the timing of a partner, is a form of interpersonal entrainment necessary to play music in ensemble. To this respect, two questions can be advanced. First, whether MAT can be seen also in non-musician populations. This might imply interesting theoretical consequences with respect to the hypothesis of an innate inter-subjective musicality. Second, whether subject's MAT can be influenced by the position of the partner's body. This might imply that MAT modulation is guided by changes in the feeling of body ownership and agency, which in turn would affect subject's cortico-spinal excitability patterns. In order to test these hypotheses, we employed an alternate joint finger tapping task (which can be easily carried out without being expert performers), while single-pulse TMS was delivered on M1. This experimental design allowed us to test MAT in non-musicians and to study cortico-spinal excitability patterns while manipulating partners' body position. Ownership and agency were tested by ad hoc questionnaires. We first found that MAT was present also in a non-musicians population and was not affected by the position of the partner, thus pointing to the universality of such a joint proto-musical competence. Moreover, cortico-spinal excitability was similar when the subject tapped alone ('solo condition') and when the subject tapped with the partner in a position congruent with the subject's body (the 'egocentric condition'). On the contrary, when the subject tapped with the partner placed in front of him (the 'allocentric' condition) cortico-spinal excitability was higher with respect to the solo and egocentric conditions. These results show that, despite the fact that the partner was present both in the egocentric and in the allocentric position, only the allocentric condition was treated as a social ensemble. Interestingly, in the egocentric condition the partner's body seemed to be treated as the subject's 'own' body. The subjective feeling of ownership and agency were coherent with the physiological data.

1. Introduction

In everyday life humans can reach highly sophisticated levels of spatio-temporal coordination in order to accomplish a joint-action (Sebanz et al., 2006), as exemplified by two or more individuals playing music or dancing. When such coordination brings forth a rhythmic synchronization between individuals, we can observe the phenomenon of "interpersonal entrainment" (IE) (Phillips-Silver et al., 2010, Philip-Silver and Keller, 2012, Clayton, 2012). While "entrainment" is the dynamic of attraction between two not necessarily animated oscillators (like Huygens' pendulums), IE is a typically human phenomenon (for some limited exceptions see Merker et al., 2009), which may occur more or less voluntarily (Schmidt and Richardson, 2008) and is explained, either alternatively or jointly, by dynamical systems theory and mechanistic approaches" (Colling and Williamson, 2014; Kaplan and Bechtel, 2011; Jantzen 2008; Kelso, 1995). As in pendulums, the temporal dimension of IE invokes the notion of "relative phase" between two periodic events: as two pendulums carrying out a number of cycles, particular events in the case of human interactions can be periodic, for example, the relationship between the walking bass and the strikes of the snare drum in a jazz rhythm section (Doffman, 2008). If two such events occur precisely at the same time, then they are in phase (relative phase 0°), if one occurs midway between the other, they are in anti phase (relative phase 180°), but they can also maintain many other ratios, as it is manifest in the huge variety of musical meters (3:4, 5:4, 7:8 and so on) and polyrhythms.

In the rich field of studies on sensorimotor synchronization (see Repp and Su, 2013, for a review) some experiments have been recently run on IE in joint finger tapping, a task that, although implying only a very simple motor act (see Leman et al., 2017; Novembre and Keller, 2014), allows for an investigation of the phenomenon also in samples of non-experts. Konvalinka et al. (2010), for example, observed in pairs of non-musicians the capacity to adapt their timing to each other in a finger tapping in-phase task with the metronome, provided that acoustical feedback went in both directions (from one subject to the partner and vice-versa) and from the subject to himself. The authors named "hyperfollower" the unity that emerged from this task. On the contrary, Nowicki et al. (2013) tested a sample of musicians, rather than non-experts, in an alternate tapping task. The choice of an expert sample may be due to the fact that alternate tapping is harder than a synchronous tapping (indeed, in-phase synchronization is more stable than anti-phase synchronization, Repp and Su, 2013). Following Philip-Silver and Keller (2012) suggestion, we can say that, while synchronous tapping can be attributed to chorusing (a musical joint-action in which individuals make equal contribution, like monophonic and homophonic textures), alternate tapping is a form of turn-taking (a complementary joint-action, like call and response in antiphonae or gospel singing), the latter representing a more complex form of joint-action.

Also Nowicki et al. (2013) found a kind of mutual adaptive timing (MAT) in the pairs of musicians they studied by means of cross-correlations of the temporal series of asynchronies of each partner's tapping relative to the pacing signal, provided that the acoustical feedback went in both directions (while the visual feedback turned out to have a negligible influence). In particular, rather than correcting their partner's asynchronies (compensation), subjects tended to follow them (assimilation), that is, they were late or early relative to the metronome, if their partner was himself late or early. As stressed by the authors: "Members of the (musical) ensemble must coordinate their performance with this basic pulse, as well as with each other's sounds, to achieve a well-synchronized holistic musical interplay" (ibidem). But, and this is our first research question, is such a competence a prerogative of musicians (as a consequence of expertise and exercise) or can it be observed also in non-musicians? If the latter is the case, we might argue that such a form of IE (MAT, by no means the only form) is at the basis of the human rhythmic behaviour, representing a prerequisite rather than an outcome of the musical education, thus strengthening the hypothesis of an innate inter-subjective musicality (Wallin et al., 2000; Levitin, 2006, Molloch and Threvarten, 2009; Honing et al., 2015; Leman, 2016).

The second research question we posed is the following: can a manipulation of the feeling of body ownership (i.e. the sensation that the body or a body part is mine, Blanke et al., 2015; Pia et al., 2016; Garbarini et al., 2014; Garbarini et al., 2015; Fossataro et al., 2016; Fossataro et al., 2017a, 2017b) and agency (i.e. the sensation that a certain action is accomplished by me, Haggard, 2017, Piedimonte et al., 2013, Garbarini et al., 2013) affect the phenomenon of IE? In other words, can IE-MAT be modulated by veridical or non-veridical attribution (to me or to my partner) of the motor act involved in the rhythmic performance?

Body ownership and the sense of agency can be manipulated to a degree that a subject can feel that an external object (and its action) becomes part of his/her own body. One of the most used experimental paradigms that induces this delusion of ownership is the rubber-hand-illusion. Such illusion occurs when a rubber arm is placed in a position congruent with the subject's body and internal with respect to the subject's real hand, which is hidden from view and stimulated with a brush while another brush is touching the rubber hand (Botvinick and Cohen, 1998). If the tactile stimulation on the two hands is synchronous, the rubber hand gets embodied after a few seconds, that is, the subject feels as if it has become part of his/her own body and, if it moves, as if the subject is the author of that movement. Schutz-Bosbach et al. (2006) used a paradigm similar to RHI by delivering synchronous or asynchronous visuo-tactile stimulation to the subject's hand and to the co-experimenter's hand. After the RHI procedure, Motor-Evoked Potentials (MEPs) to Transcranial magnetic Stimulation (TMS) were recorded from the right first dorsal interosseus (FDI) muscle during an action-observation paradigm, in which the co-experimenter moved her/his fingers. They found that, after asynchronous stimulation (when the embodiment did not occur), MEP amplitude, registered from the own hand, increased, as it is usually observed in the action observation paradigm (Fadiga et sl, 1995). Indeed, Fadiga et al. (1995) in a seminal paper, using single-pulse TMS on the primary motor cortex (M1), found that cortico-spinal facilitation occurred whenever a subject observed someone acting on an object (e. g. during a grasping action), compared to when he/she simply looked at it. This showed that the observer's motor system immediately activates when another subject is performing a finalised motor act, and in a similar way with respect to when the observer moves himself. Therefore, according to these data in the Schutz-Bosbach experiment (2006), when the experimenter's hand was correctly treated as 'alien', that is as belonging to some other person, the motor system responds in the mirror like fashion, with an increased activity of the cortico-spinal system. On the contrary, after synchronous stimulation (when the experimenter's hand was embodied), identical observed actions, now illusorily attributed to the subject's own body, did not produce any motor facilitation (i.e the MEPs amplitude was unchanged with respect to the baseline). The absence of MEP modulation during movement observation following synchronous stimulation can be interpreted as a motor pathways inhibition for own action observation (Ehrsson et al., 2004; Della Gatta et al., 2016). These data show that the motor system has the resources to distinguish between the self and other's body/action (Schutz-Bosbach et al., 2006, but see Decety and Chaminade, 2003).

The findings discussed above suggest that when a subject looks at the other's hand movement at least two mechanisms can be activated depending on the ownership ascribed to that hand. Usually, if the observed moving hand is considered to be part of someone else's body, a cortico-spinal facilitation of the own hand is observed due to the mirror neurons system activation (as in Fadiga et al., 1995, and in Schutz-Bosbach et al., 2006). On the contrary, if the other's hand is, under certain manipulations, embodied in the subject's body representation, (as in the RHI and similar paradigm), a cortico-spinal inhibition for the own hand is observed, as if the own hand is disembodied (Ehrsson et al., 2004; Della Gatta et al., 2016). Moreover, as already mentioned, when two (or more) people are involved in the same motor context, a 'joint action' can be pursued and the mirror neuron system is one of the brain networks that activate in joint action context (Masumoto and Inui, 2014; Keller et al. 2014; Zatorre et al. 2007).

Novembre et al. (2012), using a musical experimental paradigm, created a joint action context where they let a sample of pianists learn a number of Bach's chorales and afterwards tested them in the following three conditions: participants performed with the right hand the melody alone; they performed the melody with the right hand while a hidden partner was performing the bassline with the left hand (a recording, actually); they performed the melody persuaded that the hidden partner was performing the bassline, but without acoustic feedback. In both joint conditions (with or without sound) the authors found higher cortico-spinal excitability – as indexed by the amplitude of the MEPs recorded from the left FDI, ADM (abductor digiti minimi) and ECR (extensor carpi radialis) – than in the condition in which the pianists played alone. This is, therefore, an example where the motor system seems sensitive to the sociality of the context, activating more complex action plans, which take into account the other as a potential co-actor. The authors conclude that the facilitation effect observed in the joint condition, rather than reflecting a "copy" of the movements associated with the left-hand part, could be taken as a social modulation of the motor system via mirror neuron' system activation.

To summarize, when two individuals act in the same context, the motor system facilitation/inhibition seems to depend either on the ownership attribution and/or on the sociality of the context. In the first case (ownership attribution) an embodiment mechanism, as that induced by the RHI paradigm, would imply a cortico-spinal inhibition of the own 'disembodied' hand, once that the 'alien' hand is incorporated.

In the second case (sociality of the context), a 'mirror' mechanism would be triggered, that implies the activation of the motor system of the observer when a partner is implementing a finalised action. This would entail an increment of MEP's amplitude in the observer as part of a shared motor situation.

In the present work we took advantage of an alternate joint-tapping task to investigate 1) the capacity of non-musicians to give rise to anti-phase MAT-IE and 2) the possibility that such phenomenon is modulated by the position of the partner's hand (egocentric vs allocentric position) with respect to the subject: the egocentric position is the one in which embodiment may occur (e.g. Bucchioni et al., 2016) while the allocentric position is the one in which we perceive the body parts of others in every day life (e.g. Fossataro et al., 2016). One important aspect of our experiment is the real interaction it implies, while Novembre et al. (2012)' set-up had pianists playing with a recording. We first asked subjects to practice, bimanually, alone, alternating tapping with their right and left index finger on two drum pads endowed with a snare and a bass drum sound respectively, at 120 bpm metronome (the preferred tempo for many human movements, van Noorden and Moelants, 1999). Such a practice reproduces in a hyper-simplified way Novembre et al. (2012) learning phase of the piano chorales. Afterwards, in order to get a measure of motor system excitation, MEPs were recorded (from the FDI of the left hand at rest) while participants performed the task in the following three conditions: solo, allocentric (they tapped in alternation with the partner, one in front of the other), egocentric (subjects tapped in alternation with the partner, who stayed in a position congruent with the subject's body). Moreover, subjects had to answer to a Likert-scale questionnaire about the sense of agency and ownership in both joint conditions.

First, if non-musicians are able to assimilate their timing to the timing of the partner, the correlation values of the allocentric condition should be positive and higher than those of the solo condition. As regards to the partner's position, we expected to see higher cortico-spinal excitability when the partner is in the allocentric position, due to mirror mechanisms that the shared action should activate, compared to when the subject taps alone with his/her right index finger in alternation with the metronome. On the contrary, we hypothesized that in the egocentric condition MEPs should be similar to those in the solo condition because the distinction between the self and the other may become weaker, as if there is no longer any partner to interact with. Following the same reasoning, also the behavioural outcome could turn out to be perturbed and MAT-IE could not hold anymore: if I can't distinguish my partner, I won't be able to interact with him in the effective rhythmical ways typical of ensemble music (even in the hyper-simplified way represented by tapping).

2. Materials and methods

2.1. Participants

Twenty right-handed volunteers (13 female, 7 male, mean age = 25.3 years, standard deviation = 5) took part in the experiment. One of them was excluded as outlier in the questionnaire scores. Participants were screened to exclude musical expertise and neurological or medical disease. According to the experimental procedure (see below), subjects acted together with a partner of the same gender (male with male and female with female) to avoid distress in the egocentric condition, since it implied contact between them. The participants did not know each other before and were naive with regard to the purpose of the study. None of them had history of neurological, major medical or psychiatric disorders and they were free from any contraindication to TMS (Rossi et al., 2009; Bruno et al., 2017a, 2017b). The experiment was approved by the Ethics Committee of the University of Turin and informed written consent was obtained from each participant.

2.2. Behavioural recordings

In order to record the mean asynchronies between the tapping of the subjects in the pair and the metronome beats, and then assessing if and which form of entrainment occurred, two circular drum pads (diameter 20 cm) were used linked to an Axoloti circuit board (www.axoloti.com), whose software was specifically programmed to deliver a snare drum sound on one drum pad and a bass drum sound on the other, recording their time stamps at each tap. Subjects could hear the metronome and the sound of each drum pad by means of two headphones. They were sitting on a chair and required to tap in a comfortable way with their right index finger on the drum pad placed on a table in front of them. After a short training phase, in which each of them separately had to tap on both drum pads in alternation with both hands at 120 bpm, the right pad of the subject who got brain stimulated was hidden from his/her sight by means of a cartoon barrier and he/she was asked to tap while looking only at the partner's pad. The tempo of the metronome was always set at 120 bpm and the sound of each pad was cut to last a few milliseconds.

2.3. Stimulation and physiological recordings

2.3.1. Magnetic stimulation

Motor evoked potentials (MEPs) were elicited by single-pulse transcranial magnetic stimulation (TMS) (Magstim Rapid2; Magstim Co. Ltd, Whitland, UK) with a 70-mm figure-of-eight-shaped coil positioned over the hand area of the right M1. The optimal location for stimulus induction (the location that gave the maximum MEP amplitude) for the left FDI muscle was identified. At this location, the coil was positioned and fixed with the handle pointing backwards at 45° from the midline so as to activate the selected muscle. Then, the resting motor threshold (rMT) was determined as the intensity needed to evoke a MEP in the relaxed muscle of more than 50 μV in 5 out of 10 consecutive trials. The stimulator output was set at 110% of each subject's rMT (56.04% ± 6.46%, range 46–63% of the maximum stimulator output). Participants who showed a rMT higher than 70% of the stimulator output were excluded from the stimulation phase.

2.3.2. Electromyography recording

Electromyographic (EMG) activity was recorded (MP150, Biopac System, USA), from the left first dorsal interosseous muscle (FDI) by self-adhesive bipolar surface electrodes with active electrode over the muscle belly and the reference electrode over the associated joint or tendon. Signals were amplified and digitalized with a sample rate of 10 kHz, filtered with a band-pass (10–500 Hz), and stored in a computer for offline analysis, according to methods used in previous studies (Bucchioni et al., 2016; Fossataro et al., 2017a, 2017b; Bruno et al., 2017a, 2017b, Fossataro et al., 2018).

2.4. Task and procedure

The experiment was programmed by using E-prime software V2.0 (Psychology Software Tool Inc., USA) in order to trigger TMS pulses at a controlled timing and trigger the EMG recording. After a short training phase in which the metronome was turned on and the subject was asked to synchronize with it, tapping in alternation with the right index finger on the right drum pad and with the left index finger on the left drum pad, electrodes were placed on the left FDI muscle and the left part of the body was covered with a black cape, in order to prevent the view of the own arm during the experiment. Moreover, we instructed the subject to look at their partner's pad and to start tapping after a pre-recorded voice stressed the first four beats of the metronome, trying to synchronize with the odd beats of it. Then, the experiment started in one of the following three conditions (see Fig. 1), with the order of conditions randomized across couples:

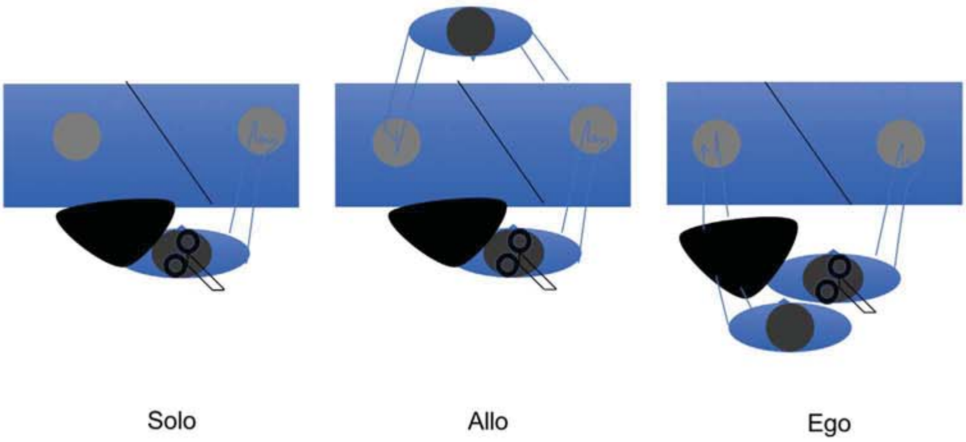

Fig. 1. Schema of the three experimental conditions. Solo (left): the subject taps alone with the metronome. Allo (center): the subject taps in alternation with the partner in front of him. Ego (right): the subject taps in alternation with the partner sitting in a position congruent with the subject's body. Single-pulse TMS is delivered on the right M1 and MEPs recorded from left FDI muscle.

1) Solo: the subject taps on his pad with the right index finger on the odd beats of the metronome;
2) Allocentric (Allo): the subject taps with the right index finger on the odd beats of the metronome, while his/her partner sitting in front of him/her taps with the right index finger on the other pad on the even beats;
3) Egocentric (Ego): the subject taps with the right index finger on the odd beats of the metronome, while his/her partner sitting beside him/her taps with the left index finger on the other pad on the even beats. In this condition, the partner taps with his/her left arm placed in a position congruent with the subject's body and covered itself, except for the hand.

In order to check for any corticospinal excitability change related to TMS per se, ten baseline MEPs were recorded before (i.e. baseline-pre) and after (i.e. baseline-post) the experimental block, each time the right index finger performed a tapping, with an interstimulus interval of 10 s. The MEPs amplitude recorded during the baseline were used to normalize data recorded during the experimental conditions.

Each experimental condition consisted of six trials of 30 s, in which participants were instructed to start on the fifth beat of the metronome and go on until a pre-recorded voice said "stop" (28 s later), gathering about 28 time stamps for each subject of the couple (tempo always set at 120 bpm). A 10 s inter-trial pause followed. Three TMS single pulses for each trial were delivered online in correspondence of the hypothetical tenth, eighteenth and twenty-fourth tap of the partner, giving a total amount of $3 \times 6 = 18$ MEPs for each condition (plus 20 baseline MEPs).

Once both subjects' motor threshold was established, the experiment took approximately 40 min, 20 min for each subject who got stimulated. It should be taken into account that sometimes one of the partners could not be brain stimulated, either because of lack of time (e.g. the search for the first subject's threshold took too long) or because his/her threshold was too high. Nevertheless, in order to correlate the time series of the pair, we recorded also the time stamps of those partners who could not be stimulated (Fig. 2).

Immediately after both the allocentric and the egocentric conditions a Likert-scale questionnaire (−3 = strong disagreement; +3 = strong agreement; 0 = neither agreement nor disagreement) about the sense of agency and ownership was administered. As for agency, the items were: "The hand I was looking at moved exactly as I wanted", "I felt as if I was in control of the movements of the hand I was looking at", "I felt as if I was causing the movements of the hand I was looking at" (these are the real questions, then we added three control items). As for ownership, the items were: "I felt as if I was looking at my own hand", "I felt as if the hand I was looking at was part of my body", "I felt as if the hand I was looking at was mine" (plus three control items).

2.5. *Data analysis*

2.5.1. *Behavioural analysis*

First, raw asynchronies for each trial were computed by subtracting the onset time of each event in the pacing metronome sequence from the nearest registered tap time. Then we addressed serial dependencies in tap timing by examining cross-correlations of asynchronies in each trial and averaging them: partially following Nowicki et al. (2013), we call "lag 1 auto-correlation" the correlation of the series of asynchronies generated by each individual alone with the same series shifted by one and "joint-correlation" the correlation of the series of asynchronies generated by co-acting members of a dyad. We will not report the results for the former measure in the current article, since we were interested in the social dimension of the task, which is mainly expressed by the latter. Neither we report mean asynchrony measures, since we were interested rather in their correlation as a mark of MAT-IE. Then, joint-correlation was the variable of interest, that is, the correlation of the series of asynchronies generated by the subject with the series of asynchronies generated by the partner. Positive values of the joint-correlation coefficient suggest a greater tendency for temporal assimilation than compensation in mutual adaptive timing, that is, a tendency to follow the direction of the partner's asynchronies with respect to the metronome (late, if the partner is late, early if the partner is early). Assimilation is a form of entrainment, whereas negative values indicate compensation, that is, correction of the partner's asynchronies. In order to have an effective measure of the joint-correlation in the Solo condition (to be compared to Allo and Ego conditions) we correlated the series of asynchronies of each subject of a pair when he/she tapped alone with the partner' series in the same condition. Then, we performed a one-way ANOVA with a within-subjects factors "condition" (three levels: Solo, Allo, Ego) and post hoc comparisons using Bonferroni's test.

As for the questionnaire, the mean value of the three ownership statements and the three agency statements used in the subjective rating questionnaire, in the allocentric and egocentric conditions, was obtained and used as a dependent variable. An outlier was removed and a paired T-test (two tailed) was performed on 19 subjects comparing Allo and Ego condition.

2.5.2. *Physiological analysis*

EMG data were analyzed offline using AcqKnowlege software (Biopac Systems, Inc., Santa Barbara, CA) to measure the peak-to-peak amplitude (in μV) and MEPs with an amplitude lower than 50 μV were discarded from analysis. Trials showing pre-activity (EMG signal greater than 50 μV) in the time window of 100 ms before the TMS pulse were excluded from analysis. Normal distribution of the residuals was checked using the Shapiro-Wilk test ($p > 0.05$) and the appropriate parametric tests were performed by Statistica Software 7 (StatSoft, Inc.,

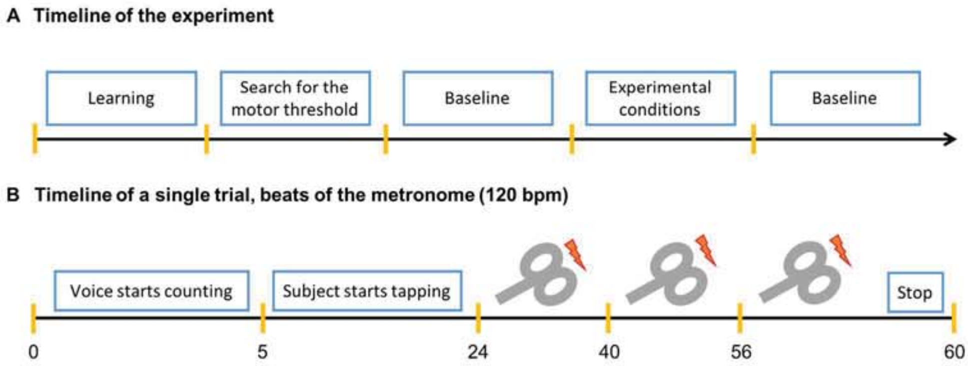

Fig. 2. Timeline with the different sections of the experiment (A). Timeline of a single trial (30 s) in beats of the metronome at 120 bpm (B).

Tulsa, UK). The mean MEPs values acquired during baseline-pre were compared to baseline-post by means of a paired T-test (two-tailed). According to the negative results in the baseline analysis, the mean MEPs amplitude of the baseline were used to normalize data of the experimental conditions. For the experimental condition a MEPs ratio (MEP ratio = $MEP_{obtained}/MEP_{baseline}$) was calculated and used as dependent variable in a one-way ANOVA with a within-subjects factors “condition” (three levels: Solo, Allo, Ego). Post hoc comparisons were carried out by means of Bonferroni test.

3. Results

3.1. Behavioural results

The serial dependencies between asynchronies generated by the pairs of non-musicians are plotted in Fig. 3.

The first thing that can be noticed is that Pearson correlation coefficients (r) for conditions ego (mean ± SE = 0.421 ± 0.038) and allo (0.424 ± 0.051) are both positive, significantly greater than zero and very similar in magnitude, contrary to the solo condition (0.044 ± 0.028). As we said, we obtained the coefficient in the solo condition by correlating the series of asynchronies generated by each partner separately, when they tapped alone in alternation with the metronome. The ANOVA found a significant effect of condition [$F(2,36) = 34.97$; $p < 0.00001$; $\eta^2 = 0.66$; power = 1]. At post hoc comparisons our results show a clear behavioural difference between solo and allo conditions ($p < 0.00001$) and between solo and ego conditions ($p < 0.00001$), but no difference between allo and ego conditions ($p = 1$) (Bonferroni correction). Since a stronger tendency for temporal assimilation than compensation is evident (the correlation value is positive, with a medium effect size), we can conclude that an entrainment in the form of mutual adaptive timing emerged.

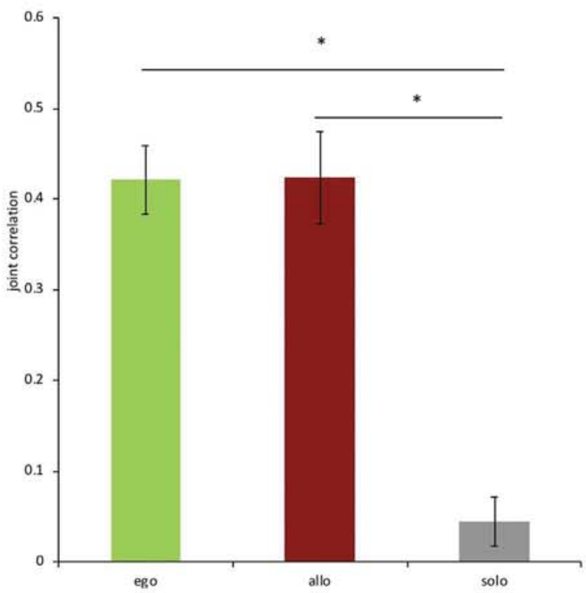

Fig. 3. Average joint-correlation of asynchronies for each condition. Error bars represent the standard error of the mean.

As for questionnaires, the ratings of ownership ($t_{(18)} = 2.635$; $p = 0.017$; $dz = 0.61$) and agency ($t_{(18)} = 2.375$; $p = 0.029$; $dz = 0.55$) of the partner's hand in the egocentric condition were significantly higher than those in the allocentric condition, meaning that some kind of embodiment occurred in the former, but not in the latter condition (Fig. 4).

3.2. Physiological results

In the baseline analysis, the T-test (two-tailed) did not show any significant results ($t_{(18)} = 0.34$; $p = 0.73$). This suggests that TMS per se did not induce any change in corticospinal excitability and that the cortical excitability was unchanged from the beginning compared to the end of the experimental block.

The one-way ANOVA found a significant effect of condition [$F(2,36) = 5.98$; $p = 0.006$; $\eta^2 = 0.25$; power = 0.85], suggesting a different MEPs modulation between conditions. At post hoc comparisons (Bonferroni correction), contrary to the behavioural data, cortico-spinal excitability in allo condition was significantly higher compared to both ego ($p = 0.023$) and solo ($p = 0.009$) conditions. No difference between ego and solo condition was found ($p = 1$). In the plot in Fig. 5a striking similarity can be observed between solo and ego conditions, suggesting, along with the answers to the questionnaires, that a form of embodiment occurred in the latter.

4. Discussion

In the present study we investigated the phenomenon of interpersonal entrainment (IE) in an alternate joint-tapping task between pairs of non-musicians and its possible modulation according to the spatial position of the subjects in the pair. Moreover, we wanted to see whether the manipulation of the spatial position we employed could elicit embodiment phenomena, similar to those observed in the rubber hand illusion (RHI) paradigm, and whether this could affect both IE and the motor system excitability. Accordingly, we hypothesized that, using single-pulse TMS, different IE and MEPs should be registered, depending on the condition of the experiment. First, we have shown that mutual adaptive timing (MAT), one of the many forms that IE may assume (see Introduction), is not restricted to musicians, but characterizes, at least in our paradigm, also non experts' performance. Moreover, the form of IE that we found was not modulated by the partner's position in the couple, overcoming the embodiment effects due to it. Finally, we have shown that the spatial position of the partner modulates not only the feeling of body ownership and agency

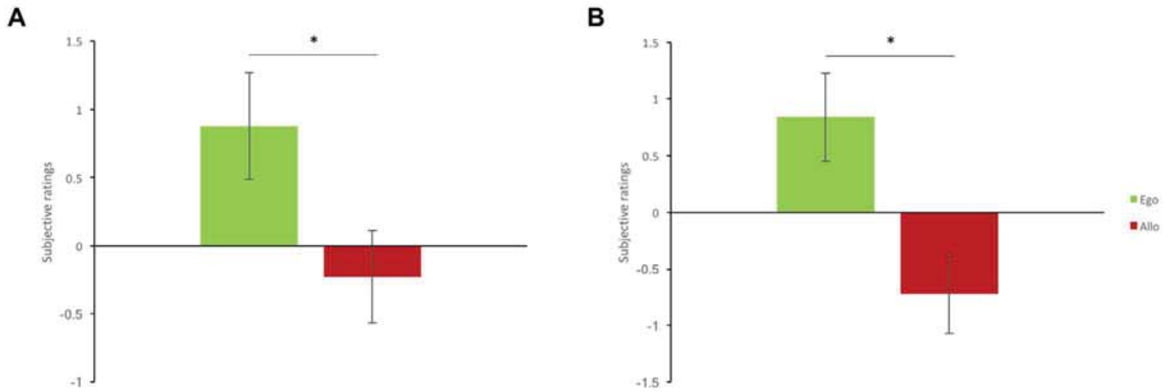

Fig. 4. Average score of the questionnaires for the feeling of ownership (A) and agency (B). Error bars represent the standard error of the mean.

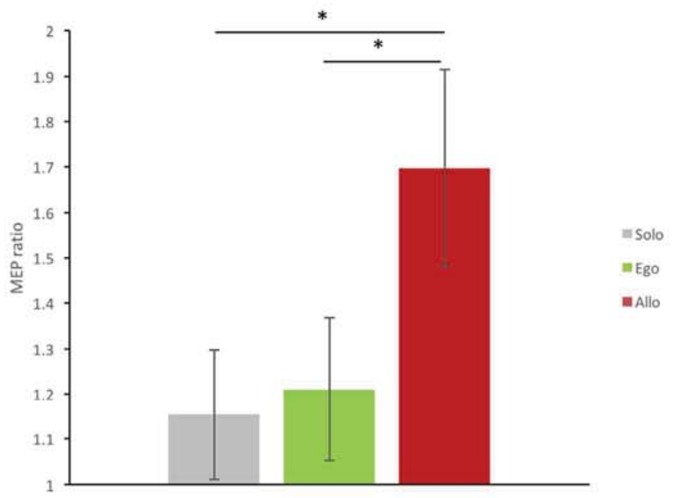

Fig. 5. Values of the MEP ratio ($MEP_{obtained}/MEP_{baseline}$) for each condition. Error bars represent the standard error of the mean.

(observing an embodiment in the ego condition, Botvinik and Cohen, 1998, Bucchioni et al., 2016), but also the physiological value of cortico-spinal excitability, according to whether the partner tapped in front of the brain-stimulated subject (allocentric position) or besides him/her, with his/her left hand in a position congruent with the subject's body (egocentric position). We will discuss each of these points separately.

The form of IE represented by MAT is an essential prerequisite to play in ensemble, along with two other cognitive competences: prioritized integrative attending and anticipatory imagery (Keller, 2008). The former is the capacity to pay attention not only to one's own musical part, but also to what the rest of the ensemble is playing, while the latter is the use of internal models to foresee not only what the musician is on the point of playing, but also what the other musicians will do in the short run. Several experiments have shown mutual adaptive timing to occur in musical contexts (Schoegler, 2000; Keller et al., 2007; Goebl and Palmer, 2009), and some studies (e.g. Nowicki et al., 2013) that used alternate tapping tasks, suggested that only expert musicians would show it. Actually, Nowicki et al. (2013) only tested expert musicians on the possible assumption that anti-phase synchronization would be too difficult for non-expert (see also Repp and Su, 2013). Nevertheless, in the present study we found a similar IE effect also in non-musicians. This is a very interesting outcome because, suggesting a universality of IE-MAT, it indicates that it is a prerequisite for playing in ensemble, rather than a result of the long sensorimotor training that every musician has to complete before mastering an instrument, at least in our culture. Leaving aside the rich debate on the possible evolutionary origins of music (Wallin et al., 2000; Honing et al., 2015), we would like to stress that (almost) every society has developed some form of music and that, contrary to modern societies, primitive societies show little difference between music producers and consumers. Therefore, it is not surprising that when non-musicians (who can be considered more consumers than producers) tap in alternation with the pacing signal of the metronome, they are able to adapt their timing to their partner's (see also Koelsh et al., 2000).

Interestingly, this capacity seems to be somehow unconscious since, as phase-error correction (Repp and Su, 2013), it happens on a milliseconds timescale and without any explicit instruction for the two subjects to reciprocally synchronize (in fact, subjects were asked to synchronize with the metronome only). This 'automaticity' behind IE-MAT may be a further argument for assuming its 'universality'. Crucially, the IE-MAT was not modulated by the 'embodiment' of the partner's hand in the ego condition. This finding seems again to suggest that IE-MAT is not bonded to the supposed 'agent' of the action, but, instead, is apparently governed by the intrinsic characteristic of the joint proto-musical system, overlooking the mechanisms responsible for the self-other distinction.

As it is a lot more evident in a real musical context (Cross, 2014), also in our set-up the regular pulse of the metronome along with the beats produced by tapping on the two drum pads outline a sort of basin of attraction (Leman, 2016) around which participants share attention, cognition and action. Several studies have recently stressed how being and keeping together in time (McNeill, 1995; Overy and Molnar-Szakacs, 2009) may induce a sense of affiliation, blurring the self-other distinction (Hove and Risen, 2009). Such a capacity for strengthening the social bonding, such "bio-technology of group formation" (Freeman, 2000), leads us to consider music, or at least musicality, as an eminently inter-subjective phenomenon. In this respect, the philosopher Elizabeth Pacherie (2012), in her phenomenological analysis of joint-action, has distinguished a SHARED sense of joint-agency from a WE sense of joint-agency: in the former kind, participants in the joint-action have different roles and their actions are complementary, whereas in the latter kind, roles and actions tend to be so similar that the sense of the (acting) self may weaken, in favour of a super-ordinate unity. The IE that we have found also between two non-musicians might be explained by this mechanism of WE sense of joint-agency, whose physiological markers have still to be identified. A clue could be found in Fairhurst et al. (2013), who, using fMRI, assessed an optimal range of synchronization and mutual adaptive timing between a tapping subject and his (virtual) partner, characterized by the activation of the Default Mode Network (cortical midline structures in conjunction with premotor areas), whereas different ranges activated right lateral prefrontal areas associated with central executive control processes. Contrary to the latter, the activation of the former mechanism points toward a fluency of the (proto-musical) interaction and, again, toward a blurring of the self-other distinction. This could be due also to the higher predictability of the optimal synchronization condition.

Actually, Bolt and Loehr (2017) recently showed that the rating of SHARED agency in a tone sequence production was higher the more predictable was the partner of the joint action.

Another important finding of our experiment is that the spatial position of the partner's tapping hand seems to modulate both the sense of ownership and the sense of agency in a way similar to that usually found in the RHI paradigm. Indeed, the results of the questionnaires we proposed to our participants show that in the egocentric condition (but not in the allocentric condition) subjects reported the feeling that the alien hand belonged to themselves and that they were the agent of the tapping action. Accordingly, we have found that cortico-spinal excitability for the own hand, as indicated by the MEPs value, was very similar in ego and solo condition. It is worth noting that we obtained these results without following the classical procedure to induce the RHI. In this respect other studies have shown this possibility (Kalckert and Ehrsson, 2014). Similar results were found by Schutz-Bosbach et al. (2006). They used the RHI paradigm in order to determine if and how the motor system has the resources to distinguish between the self and the other's movements. Once the embodiment of the partner's hand was induced (in the synchronous condition), the MEPs facilitation, usually present during action observation paradigm and replicated in the no-embodiment (asynchronous) condition of their study, was abolished and no difference with respect to the baseline was found. Even more interesting, in our study, is the finding that MEPs increased in the allocentric condition, indicating an increase in the cortico-spinal excitability. In keeping with our predictions, this indicates that the proto-musical context of our experiment has the characteristics of a (proto-musical) joint action, that is, of a motor act that, through the social interaction with the partner, aims at reaching the required rhythmic alternation. The higher cortico-spinal excitability in the allocentric position is in accordance with Novembre et al. (2012)' study in which pianists, though in an exclusively acoustic condition, showed higher MEPs in left FDI, ADM and ECR when they performed the right part of a piano piece together with a hidden partner performing the left part, rather than performing it alone. Actually, Novembre et al. (2012) found the same facilitation pattern in a 'mute' condition, in which the pianist playing the melody could not hear his partner playing the bass-line. Then, in this case, we can exclude that eco-neurons (auditory mirror neurons which activate when an action is simply heard, as if that action is accomplished by the observer himself, Kohler et al., 2002) played any role. But, since both joint-conditions, ego and allo, included auditory feedback, and only the latter showed a different excitability pattern, this remark can be extended to our experimental setting: eco-neurons are neither a necessary nor a sufficient condition to elicit higher MEPs.

It is worth noting that, contrary to our results, Maeda et al. (2002) found that MEPs' amplitude for hand movements in allocentric condition (hand pointing toward the observer) were lower than MEPs recorded in egocentric condition (hand pointing away from the observer). However, in the Maeda et al.'s experiment both conditions were shown on a computer screen, that is, in a context which was even less ecological than ours and those discussed previously (Schutz-Bosbach et al., 2006; Della Gatta et al., 2016): an image on a screen versus a more (a real hand) or less (a fake hand) biological object. In our experimental setting the social affordances (Knoblich and Sebanz, 2008, Gallese and Sinigaglia, 2010) offered by a partner in an allocentric condition, the possibilities of enacting a joint (proto-musical) action, are quite richer than those offered by a partner in an egocentric position (least of all on a screen). This is possibly the reason why in the latter case MEPs turned out to be lower, while the sense of agency and ownership was higher, exactly as in the solo tapping condition.

Now, an interesting question that deserves further exploration is whether the phenomenon we are dealing with can be framed within the "minimal architecture for joint-action" (Vesper et al., 2010; Butterfill, 2017). According to this model, a joint-action is made possible by three factors: representations, processes and "coordination smoothers", the first one being the goal of a joint-action (e.g. playing together), the second one being monitoring and predicting the unfolding and the outcome of such action (e.g. checking for rhythmic coherence of the ensemble), the third one being any behaviour facilitating the accomplishment of the action (e.g. slowing down one's own time, if it is perceived as faster than the other musicians' time). In our experiment the task wasn't explicitly social, in that participants were only told to synchronize to certain metronome beats (either the odd or the even beats), then a representation of the action as a joint-action wasn't explicitly required. Let's compare our task with Loehr and Vesper (2015) experiment in which a pair of non-musicians was instructed to learn either the melody or the accompaniment part of a simple piece of music. Once learned, each subject was asked to play its part either alone or with his/her complementary part. The authors take the higher rate of errors in the former condition (compared to the latter condition) as evidence that a co-representation of the joint-action was active, leading the subject to produce more mistakes in the alone condition. Nevertheless, both the behavioural and the physiological outcomes in our set-up suggest that an implicit shared motor representation emerged, insofar as mutual adaptive timing and high cortico-spinal excitability are well known markers of a social interaction. Moreover, such interaction can be conceived of as a special kind of bimanual action, in which "anticipation of another's action and preparation for your own are not two separate things [...] in the same sense that, in preparing to perform a bimanual action, preparation for the actions to be performed by the left hand and anticipation of the movement of the right hand are parts of a single process" (Butterfill, 2017, for some empirical evidence see Kourtis et al., 2013, 2014). However, it is important to notice that in our egocentric condition (the most similar to a bimanual action), the cortico-spinal excitability was comparable to the solo condition, that is, to a condition that doesn't require coordination with any other agent (be it one's own left body part or someone else's), contrary to our allocentric condition.

5. Conclusion

In conclusion, our experiment showed that IE as MAT can be found also in non-expert musicians and it is still present when the spatial position of the partner's body affects the sense of body ownership and agency, thus indicating a universal value of such a form of proto-musical competence. Moreover, we showed that when the context induces an embodiment of the partner's hand, the subject's cortico-spinal excitability is similar to the solo condition. However, when the tapping is carried out with the partner in the allocentric condition, not only the body ownership and agency are not affected, but the subject's cortico-spinal excitability increases. This is a very interesting result because it shows that, while in a joint-tapping task the motor system distinguishes between the body self and the other's body, when a subject performs an action which is strongly related to the partner's action, a shared motor representation is activated in order to deal with the social context in which individuals co-act, possibly mediated by the mirror neuron system.

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Disclosure statement

The authors have no disclosures or conflict of interest.

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