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Entrainment beyond embodiment

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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, Phillip-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,

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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.