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Individual and dyadic rope turning as a window into social coordination

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ABSTRACT

The spontaneous and intentional movement coordination between peoples is well understood. Less is known about such interactions when the coordination is subordinate to the task and when the task involves, next to vision, mechanically induced haptic and kinesthetic coupling between dyadic partners. We therefore investigated dyadic jump rope turning. Fifteen dyadic pairs conjointly turned a jump rope to which five markers were equidistantly attached, and whose movements were recorded in 3D. In addition, each participant turned one side of the rope while the other side was quasi-fixed in an individual baseline condition. The participants' goal was to turn the rope regularly and smoothly. Individual spontaneous turning frequencies differed substantially across participants. Yet, dyadic pairs spontaneously turned the rope at a common frequency, indicative of frequency entrainment. The dyadic rope rotations were less variable despite weaker between near-hand marker coordination than the individual rope rotations, and the degree of performance improvement was most pronounced for participants who were paired with a partner who performed better in the individual condition. The direction and relative strength of the coupling between partners varied substantially across dyads, but the degree of coupling asymmetry had no substantial effect on the rope tuning quality. The absolute degree in which dyadic partners adjusted to each other, however, scaled moderately with their turning performance. Although the individual performances did not predict the dyadic performances, the difference in individual performance between dyadic partners had some predictive value for the dyadic performance. In combination, these results indicate that the partners were functionally adapting to each other in order to satisfy the task goal and suggest that the relative performance differences rather than the individual performances has predictive value for conjoint action.

1. Introduction

The investigation of how individuals interact and conjointly perform tasks has been pursued along various lines (cf. Schmidt, Fitzpatrick, Caron, & Mergeche, 2011). One approach that has become quite popular over the last decades holds that a common

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coding, or representational format, underlies action and perception (Prinz, 1997; Sebanz, Bekkering, & Knoblich, 2006), which enables actors and observers to share representations. This, in turn, permits individuals to predict the timing and outcome of perceived actions, as well as establish and maintain inter-individual coordination by integrating another's anticipated action into one's own (Knoblich, Butterfill, & Sebanz, 2011; Sebanz et al., 2006). An alternative, dynamical approach explicitly seeks to identify the phenomenological laws underlying the formation of behavioral (coordination) patterns, and answer the question of whether and under what conditions individuals adapt their movements to each other spontaneously or in accordance to specific task instructions. This latter approach, which was initially developed in the context of intra-individual inter-limb coordination (Beek, Peper, & Stegeman, 1995; Haken, Kelso, & Bunz, 1985; Kelso, 1995; Turvey, 1990), has repeatedly shown that when two individuals simultaneously perform and perceive each other's rhythmical movements, the coordination between them is confined to a limited number of coordination modes (Richardson, Lopresti-Goodman, Mancini, Kay, & Schmidt, 2008; Schmidt & O'Brien, 1997; Turvey, 1990; for a review, see Schmidt & Richardson, 2008). For instance, in their paradigmatic study, Schmidt, Carello, and Turvey (1990) asked paired participants to swing one of their legs while looking at the other participant's swinging leg. In a series of experiments they found that the in-phase swinging mode was more stable than the anti-phase mode and observed transitions from the anti-phase mode to the in-phase one (but not the reverse) with increasing movement frequency as well as signs of hysteresis. Indeed, for comparable experimental settings, the same coordination phenomena as observed in individual inter-limb coordination (i.e., differential stability of the in-phase and anti-phase pattern, phase transitions, hysteresis, etc.; see Kelso, 1995, for a review) appear in inter-individual limb coordination, even though the coupling between the moving components is weaker in inter-person than in intra-person coordination (Richardson et al., 2008; Schmidt, Bienvenu, Fitzpatrick, & Amazeen, 1998). Regardless, the key observation, namely that there are only a few states in which the partners' coordinated behavior is found most of the time, and that this is largely independent of whether the coordination is established intentionally or arises spontaneously, has since been confirmed in numerous studies (see Schmidt & Richardson, 2008, for a review).

Although the research on social coordination has generated important insights – above all, that social coordination constitutes a pattern formation process – it remains yet to be seen to which degree several of its key phenomena can be generalized across the multitude of tasks that two individuals may perform conjointly (Lagarde, 2013; Richardson et al., 2015). In that regard, the task context that initially inspired many studies deviates from daily inter-individual tasks in several ways. First, in paradigmatic social coordination studies, the dyadic partners either do not strive to achieve a common goal (they merely oscillate their limbs) or the goal is defined in terms of particular coordinative states (for instance, 'oscillate your limbs in phase'). In these cases, means and ends collide. In ordinary tasks the actors typically move together with the aim to co-jointly achieve a common goal, such as to displace furniture, dance a tango, or play doubles in racket sports, to name a few. In such cases, coordinated movement is a means to an end. An example of the latter case is crew rowing, where the aim is to transfer energy into boat velocity, and which is done more efficiently in the anti-phase coordination mode than in the in-phase mode (de Brouwer, de Poel, & Hofmijster, 2013). Another documented example is inter-personal aiming (Mottet, Guiard, Ferrand, & Bootsma, 2001), in which two individuals together perform a Fitts' task (Fitts, 1954; Fitts & Peterson, 1964). In the joint task version, one person moved the pointer as the other moved the targets, and the participants spontaneously adopted an anti-phase coordination between the pointer and target movements, particularly so when the accuracy constraints were severe. Second, while in many tasks successful performance requires a certain degree of synchrony between the two partners, maximizing synchronization (but not coordination) may hamper task success in other tasks. For instance, Masumoto and Inui (2013) studied interpersonal periodic force production. They reported that dyads performed the task by synchronizing their force production, but at the same time, were complementary in terms of the amount of force generated. That is, low maximal forces generated by one partner were associated with high maximal force generated by the other partner. This strategy thus entails an anti-correlation in the force amplitudes produced. Similarly, any 'signaling' of one partner of his/her intentions to the other (Sacheli, Tidoni, Pavone, Aglioti, & Candidi, 2013; Vesper, Van Der Wel, Knoblich, & Sebanz, 2011) by definition entails a departure from (perfect) synchrony. In fact, the latter example can be cast in terms of symmetry breaking, that is, the deviation from perfect similarity of the coordinating components (be it due to structural/physical or task constraints; Lagarde, 2013). Third, in most studied instances of social coordination, the coupling between the two actors is visual. While vision undoubtedly plays an important role in many tasks performed conjointly, there are multiple instances where one actor obtains information about the other's activity through haptic (e.g., Ganesh et al., 2015; van der Wel, Knoblich, & Sebanz, 2011) as well as auditory information, as is typically the case in musical performances (Chang, Livingstone, Bosnyak, & Trainor, 2017; Keller, Novembre, & Hove, 2014). Different time scales are associated with information stemming from and flowing through different (sensory) media. For instance, the delays associated with vision and proprioception are estimated to be about 100–120 ms and 50–60 ms, respectively (Cameron, de la Malla, & López-Moliner, 2014). Whether the effect of a delay is facilitative or disruptive depends on the value of the delay relative to the predominant task-inherent time scale involved (Tass, Kurths, Rosenblum, Guasti, & Hefter, 1996). These differences notwithstanding, in paradigmatic sensorimotor coordination tasks people are readily able to establish a 0° (and 180°) relative phasing with a periodic sensory event regardless of whether the latter is visual and/or auditory and/or or haptic, even though the stability of the performed pattern depends on the modality of the event (Armstrong & Issartel, 2014; Elliott, Wing, & Welchman, 2010; Kelso, Fink, DeLaplain, & Carson, 2001; Lagarde & Kelso, 2006; Repp & Penel, 2004; Varlet, Marin, Issartel, Schmidt, & Bardy, 2012). That is, in these experimental paradigms it matters little if at all through which medium the coupling is achieved. In more ecological task settings, however, deviations from the paradigmatic observations have been reported. In crew rowing, already mentioned above, the partners are mechanically coupled through the boat. Cuijpers and colleagues reported that the in-phase and anti-phase pattern were equally variable, even though the deviation from the intended relative phase was larger in the anti-phase pattern than in the in-phase pattern (Cuijpers, Zaal, & De Poel, 2015). In addition, they observed a significant effect of stroke rate, which varied between 30 and 36 strokes per minute, on the variability of the coordination between handle positions but not between the rowers' trunks. In a follow-up study in