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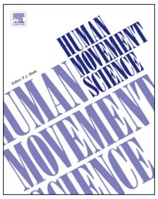

Full Length Article

Division of labor as an emergent phenomenon of social coordination: The example of playing doubles-pong

Niek H. Benerink[a,b], Frank T.J.M. Zaal[c], Remy Casanova[a], Nathalie Bonnardel[b], Reinoud J. Bootsma[a,*]

[a] Aix-Marseille Univ, CNRS, ISM, Instit Movement Sci, Marseille, France
[b] Aix-Marseille Univ, PsyCLE, Aix-en-Provence, France
[c] University of Groningen, University Medical Center Groningen, Center for Human Movement Sciences, The Netherlands

ABSTRACT

In many daily situations, our behavior is coordinated with that of others. This study investigated this coordination in a doubles-pong task. In this task, two participants each controlled a paddle that could move laterally near the bottom of a shared computer screen. With their paddles, the players needed to block balls that moved down under an angle. In doing so, they needed to make sure that their paddles did not collide. A successful interception led to the ball bouncing back upwards. Importantly, all communication other than through vision of the shared screen was excluded. In the experiment, the initial position of the paddle of the right player was varied across trials. This allowed testing hypotheses regarding the use of a tacitly understood boundary to divide interception space. This boundary could be halfway the screen, or in the middle between the initial positions of the two paddles. These two hypotheses did not hold. As an alternative to planned division of labor, the behavioral patterns might emerge from continuous visual couplings of paddles and ball. This was tested with an action-based decision model that considered the rates of change of each player's angle between the interception axis and the line connecting the ball and inner edge of the paddle. The model accounted for the observed patterns of behavior to a very large extent. This led to the conclusion that decisions of who would take the ball emerged from ongoing social coordination. Implications for social coordination in general are discussed.

1. Introduction

Many activities in daily life involve coordination with other individuals. When walking down a street, we not only need to avoid collisions with street furniture, but also need to navigate among other pedestrians. We all have been in situations in which we approach another pedestrian head-on and are both not sure who will go in which direction. How will coordination play out? Also in many sports situations, coordination among players and objects (often balls) is needed for a successful outcome. Obviously, in team sports like soccer this is at the heart of the game. The team has to act as a coordinated system to reach their shared goal, which is to outperform the opponent team. Some of that coordination is based on rules and pre-arranged (tactical) plans (e.g., Eccles, 2010). In soccer, when dealing with an attacker approaching with the ball on the foot, the defenders typically have instructions of who will take on that player. Analogously, in an example from a traffic context, when simultaneously approaching a four-way stop, each car

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[*] Corresponding author at: Institut des Sciences du Mouvement – UMR 7287, Aix-Marseille Université, CNRS, 163 avenue de Luminy – CP 910, 13288 Marseille cedex 09, France.

E-mail address: reinoud.bootsma@univ-amu.fr (R.J. Bootsma).

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needs to come to a full stop, and the ensuing order of crossing is typically negotiated on a first-to-arrive first-to-cross basis. Still, much of the coordination that we are involved in takes place without any clear plan of action. For example, when entering the highway, merging into traffic behind or in front of an upcoming car usually is a matter of nonverbal communication between the drivers (often signaled only through car motion and not through visual contact between drivers per se). The present study investigates this type of everyday social coordination.

Social coordination has been studied from many different angles. When moving together rhythmically, social coordination can be understood as entrainment, typically leading to one of a small number of stable coordination patterns (Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007; Richardson, Marsh, & Schmidt, 2005; Schmidt, Bienvenu, Fitzpatrick, & Amazeen, 1998; Schmidt, Carello, & Turvey, 1990; Schmidt & Turvey, 1994; van Ulzen, Lamoth, Daffertshofer, Semin, & Beek, 2008). The stability phenomena associated with this entrainment are fully in line with those known to exist in intrapersonal coordination (e.g., Haken, Kelso, & Bunz, 1985; Kelso, Holt, Rubin, & Kugler, 1981; Kugler & Turvey, 1987; Turvey, 1990), with the coupling between the individuals being informational, through vision. Other studies have considered physical couplings (e.g., De Brouwer, De Poel, & Hofmijster, 2013; Harrison & Richardson, 2009) and shown that resulting coordination patterns are essentially the same as those with a visual coupling, implying that the neural substrate is not the determining factor for understanding the coordination patterns. Although studying the characteristics of rhythmic social coordination patterns has been very fruitful (see Schmidt & Richardson, 2008, for an overview), many behaviors also have supra-coordinative goals. Studying two participants individually performing reciprocal pointing movements confronted with a complementary collision-avoidance task, Richardson et al. (2015) showed that also in this case a small set of stable coordination patterns can be observed, again emerging from a visual coupling of the two individuals. Whereas in daily life, gaze and verbal communication might be used to support coordination (cf. Clark, 1996; Knoblich, Butterfill, & Sebanz, 2011), these types of communication were not necessary to attain successful coordination in the reciprocal pointing task. In fact, plenty of situations ask for such fast adaptations to changing circumstances for which slower forms of communication such as deliberation or gaze signaling would not be sufficient (see for instance, Correia et al., 2012; Craig & Watson, 2011, for examples from rugby settings). The present study considered a time-pressured, discrete task in which two participants had the shared goal of intercepting approaching targets under a collision-avoidance constraint.

Benerink, Zaal, Casanova, Bonnardel, and Bootsma (2016) recently introduced the doubles-pong paradigm to study joint decision-making. Teams of two participants sat in front of a shared screen, on which a ball would move from top to bottom along a rectilinear trajectory. Each participant controlled a paddle that could move laterally along a horizontal interception axis just above the bottom of the screen. Apart from each of the two players being able to see both paddles and the ball moving across the screen, no other form of between-player communication was allowed. The task for the team of players was to intercept as many balls as possible, while avoiding contact between their paddles (as these then immediately disintegrated). In performing the task together, all teams showed a rather systematic division of interception spaces in that the left participant intercepted the majority of balls arriving at the left side of the screen and the right participant intercepted the majority of balls arriving at the right side of the screen. One way of considering the task that each pair of participants was faced with on each trial was that they needed to decide, among the two of them, who would be the one going to intercept the ball. From such a decision-making perspective, one would assume that the future ball-arrival position along the interception axis would determine the choice of the recipient. For instance, the rule could be that the ball would be for the player whose paddle's starting position is closest to the arrival position of the ball (according to the same logic underlying a characterization of spatial interactions by means of a Voronoi diagram; e.g., see Fonseca, Milho, Travassos, & Araújo, 2012). For such a strategy to be feasible, players need to be able to predict with reasonable accuracy the ball arrival position from early ball motion. That is to say, players would have to know early during ball motion where the ball will pass the interception axis to be able to use this knowledge to decide among them who will intercept. Although a number of studies have indicated that the control of interception does not seem to be based on early prediction of a future interception location and time (e.g., Bootsma, Ledouit, Casanova, & Zaal, 2016; Fajen & Warren, 2007; Ledouit, Casanova, Zaal, & Bootsma, 2013; Michaels, Jacobs, & Bongers, 2006; Peper, Bootsma, Mestre, & Bakker, 1994), for the present purposes we will leave aside this discussion and accept that one solution that the team of players might use for the task at hand is to divide up interception space and decide who should perform the interceptive action on the basis of the ball's estimated future arrival position.

An alternative to such an interception space-based division of labor would be emergent coordination. Rather than assuming the existence of a (explicit or implicit) predefined boundary between interception spaces of the two players (implying that the boundary would determine — that is, precedes — the division of space), emergent coordination would give rise to a division of space that, subsequently, happens to be accompanied by an experimentally observable boundary. In other words, the players would not base their decision of who will intercept which ball on a ball's perceived future arrival position with respect to a specific boundary; rather, due to the coordination with each other and the ball, over trials (with varying ball trajectories), interception regions for both players will become visible and, as a consequence, a post hoc boundary can be experimentally determined. Just as coordination patterns were shown to emerge in the rhythmical tasks discussed before (e.g., Richardson et al., 2015; Schmidt et al., 1990), the boundary between interception regions emerges from the dynamics of the system of two players' paddles and a ball. Actually, this alternative of an emergent boundary is what Benerink et al. (2016) suggested to be at play. They provided several indications of why this was considered most probable. First, although a boundary between interception spaces could indeed be distinguished in the data of each team, this boundary was in fact quite fuzzy. Second, in many cases both players initiated an interception movement, followed by one player continuing to make the interception and the other player abandoning the interception attempt. Finally, Benerink and colleagues presented a model of continuous interaction that accounted for a very high percentage of the observed phenomena. Their proposal started from the following consideration: if a paddle moves in such a way that angle β — formed by the line connecting the inner paddle edge and the ball, on the one hand, and the interception axis, on the other hand — remains constant during approach of