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# The role of action prediction and inhibitory control for joint action coordination in toddlers

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ABSTRACT

From early in life, young children eagerly engage in social interactions. Yet, they still have difficulties in performing well-coordinated joint actions with others. Adult literature suggests that two processes are important for smooth joint action coordination: action prediction and inhibitory control. The aim of the current study was to disentangle the potential role of these processes in the early development of joint action coordination. Using a simple turn-taking game, we assessed 2½-year-old toddlers' joint action coordination, focusing on timing variability and turn-taking accuracy. In two additional tasks, we examined their action prediction capabilities with an eye-tracking paradigm and examined their inhibitory control capabilities with a classic executive functioning task (gift delay task). We found that individual differences in action prediction and inhibitory action control were distinctly related to the two aspects of joint action coordination. Toddlers who showed more precision in their action predictions were less variable in their action timing during the joint play. Furthermore, toddlers who showed more inhibitory control in an individual context were more accurate in their turn-taking performance during the joint action. On the other hand, no relation between timing variability and inhibitory control or between turn-taking accuracy and action prediction was found. The current results highlight the distinct role of action prediction and inhibitory action control for the quality of joint action coordination in

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toddlers. Underlying neurocognitive mechanisms and implications for processes involved in joint action coordination in general are discussed.

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## Introduction

Social interactions shape our everyday life from birth. Central to social interactions is the way we coordinate our actions with others. Accordingly, action coordination is an essential element for joint actions that are defined as "any form of social interaction whereby two or more individuals coordinate their actions in space and time to bring about a change in the environment" (Sebanz, Bekkering, & Knoblich, 2006, p. 70). The quality of joint action coordination (i.e., interpersonal coordination of actions in the context in which the joint action occurs) largely determines the success of a joint action. Moreover, fluent coordination between people is associated with a feeling of connectedness and liking between the interaction partners (Marsh, Richardson, & Schmidt, 2009). Thus, learning to coordinate one's own actions skillfully with others enhances multiple aspects of joint actions such as success and affiliation.

There are many examples of daily joint actions that illustrate how naturally and smoothly adults coordinate their actions with others, including setting a table together, passing a cup to another person, and playing an instrument together. Common joint actions like these have been the subject of recent behavioral and neuroimaging studies (Egetemeir, Stenneken, Koehler, Fallgatter, & Herrmann, 2011; Loehr, Large, & Palmer, 2011; Ray & Welsh, 2011). Many of these joint actions involve taking turns with another person, for example, tossing a ball back and forth, beating a drum in turns (e.g., Warneken, Chen, & Tomasello, 2006), and having a conversation with another person. Coordinating actions jointly, however, is nontrivial because it requires integrating another person's actions into one's own action processing. Whereas adults display refined and proficient joint action coordination, young children still have considerable difficulties in coordinating their actions with others (for a review, see Brownell, 2011). In the current study, we examine these difficulties in children's joint action coordination and aim to provide insights into possible underlying processes of joint action coordination during early childhood.

### *Development of joint action coordination*

During their first 3 years of life, young children rapidly improve in coordinating their actions with others (Brownell, 2011). Although infants are sensitive to violations in simple turn-taking interactions with adults from 2 months (Adamson & Frick, 2003), they show hardly any form of fluent coordination with others until their first birthday unless they are scaffolded by an adult (e.g., Mendive, Bornstein, & Sebastian, 2013). Around the age of 18 to 24 months, toddlers become more successful in simple coordination tasks with adults (Warneken et al., 2006) and peers (Brownell & Carriger, 1990; Brownell, Ramani, & Zerwas, 2006). They can, for instance, simultaneously act on toys to achieve a goal together with others by the age of 2 years (Brownell & Carriger, 1990). Although there are some indications that toddlers can coordinate actions with others by 2 years, successful performance seems to be mainly restricted to tasks with low coordination demands (i.e., tasks that do not require continuous action coordination). When continuous action coordination with another person is needed (i.e., coordination exceeding a single incident of coordination to more frequent instances following each other during ongoing coordination), it takes yet another year before toddlers reach a level of joint action coordination that is similar to the level they achieve in individual coordination (e.g., Meyer, Bekkering, Paulus, & Hunnius, 2010). Whereas in individual coordination actions are coordinated intrapersonally (e.g., coordinating left and right hands), joint action coordination involves coordination between people. In a recent behavioral study, 2½- and 3-year-old children were tested in a simple coordination game

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