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Review Paper

A developmental and clinical perspective of rhythmic interpersonal coordination: From mimicry toward the interconnection of minds

Jean Xavier [a,b,*], Julien Magnat [c], Alain Sherman [d], Soizic Gauthier [e], David Cohen [a,b], Laurence Chaby [b,f]

[a] Département de Psychiatrie de l'Enfant et l'Adolescent, APHP, Groupe Hospitalier Pitié-Salpêtrière, Paris, France
[b] Institut des Systèmes Intelligents et Robotique, ISIR, CNRS UMR 7222, Paris, France
[c] Pôle de psychiatrie de l'enfant et de l'adolescent, centre hospitalier Montperrin, 109, avenue du PetitBarthélémy, 13617 Aix-en-Provence, France
[d] Department of Psychology, Northwestern University, Evanston, IL, USA
[e] CRPMS, EA 3522, Université Paris Diderot, et Equipe Berthoz, Collège de France, Paris, France
[f] Université Paris Descartes, Sorbonne Paris Cité, Institut de Psychologie, Boulogne-Billancourt, France

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ABSTRACT

Imitation plays a critical role in the development of intersubjectivity and serves as a prerequisite for understanding the emotions and intentions of others. In our review, we consider spontaneous motor imitation between children and their peers as a developmental process involving repetition and perspective-taking as well as flexibility and reciprocity. During childhood, this playful dynamic challenges developing visuospatial abilities and requires temporal coordination between partners. As such, we address synchrony as form of communication and social signal per se, that leads, from an experience of similarity, to the interconnection of minds. In this way, we argue that, from a developmental perspective, rhythmic interpersonal coordination through childhood imitative interactions serves as a precursor to higher- level social and cognitive abilities, such as theory of mind (TOM) and empathy. Finally, to clinically illustrate our idea, we focus on developmental coordination disorder (DCD), a condition characterized not only by learning difficulties, but also childhood deficits in motor imitation. We address the challenges faced by these children on an emotional and socio-interactional level through the perspective of their impairments in intra- and interpersonal synchrony.

Contents

1. Introduction

From a developmental perspective, the body, with its sensorimotor abilities, is the fundamental medium through which we interact with our environment. In this paper, we focus on motor imitation, a bodily interaction critical to the development of human intersubjectivity, particularly with respect to communication and precursory intentionality (Meltzoff and Gopnik, 1993; Nadel and Potier, 2002; Meltzoff and Decety, 2003; Rogers et al., 2005).

Imitation provides the sense of a shared experience and, according to its aspects of "social mirroring, social modeling and self-practice" in infancy, is a prerequisite of the self (Meltzoff, 1990).

* Corresponding author at: Département de Psychiatrie de l'Enfant et l'Adolescent, APHP, Groupe Hospitalier Pitié-Salpêtrière, 47-83 Bd de l'hôpital, Paris 75013, France.

E-mail address: jean.xavier@aphp.fr (J. Xavier).

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It is also a prerequisite for understanding the complex emotions, intentions, and motives of others (Gallagher, 2001; Meltzoff and Decety, 2003; Trevarthen and Aitken, 2001).

In this review, we explore, through a developmental lens, spontaneous motor imitation between children and their peers. Such interactions reveal a playful dynamic, involving repetition and perspective taking (spatial viewpoint changes), driven by continuous adaptation of behaviors, turn-taking, and position reversals (i.e. in turn imitate and being imitated, Xavier et al., 2013). These exchanges challenge the visual-spatial abilities of children and require temporal precision with flexibility and adaptation in the coordination between partners.

In this way, this dynamic process is characterized by continuous partner reciprocity involving synchrony rooted in rhythmic interpersonal coordination (Delaherche et al., 2012).

Synchrony will be presented as a form of communication and social signal per se and as a facilitator of interpersonal affinity, with an exploration of its potential to give rise to the interconnection of minds (Leclère et al., 2014). We argue that the rhythmic interpersonal coordination involved in imitative exchanges serves as a precursor to the development of empathy, the ability to share the affective states of others, predict others' actions, and stimulate prosocial behavior. Finally, we apply our idea to developmental coordination disorder (DCD), a neurodevelopmental condition characterized by childhood deficits in rhythmic interpersonal coordination and imitative abilities. We address the difficulties experienced by these children on an emotional and socio-interactional level through the perspective of their impairments in intra- and interpersonal synchrony.

2. Peer imitation in children: A rhythmic interpersonal coordination

During child development, early social interaction arises from mimicry and is present at birth (Meltzoff and Moore, 1977). In this instinctive process, an individual copies, or "mimics," the behaviors of another (e.g., facial expressions, vocalizations, movements, postures, gestures). Mimicry relies on the perception-action coupling mechanism whose neural substrate corresponds to the "mirror neuron system" (Blakemore and Frith, 2003; Iacoboni and Dapretto, 2006; Niedenthal, 2007). These neurons fire both when an action is expressed and perceived by another (Gallese et al., 1996; Rizzolatti et al., 1996). Mimicry constitutes a source of primary interpersonal engagement, a concept often referred to as "intersubjectivity" (Gallagher and Meltzoff, 1996; Gallagher, 2004), which serves important social purposes such as communication, bonding, and affiliation (Lakin and Chartrand, 2003). Intersubjectivity is also considered to be a powerful contributor to interpersonal emotional transmission (Carpenter and Nielsen, 2008).

Meltzoff (2005) explains that imitation provides evidence that observation and execution of human actions are innately coupled, with the existence of a structural congruence between the perception of others and personal behavior. Similarly, Gergely et al. (2002) contend that intentionality and the cognizance of one's own emotional states are the consequence of a continuous intersubjective "play of mirrors" between children and their parents that persists throughout development.

This imitative parental relationship also extends to the relationships between children and their peers. Between the ages of 12 and 18 months, children typically develop critical joint attention abilities that establish a perceptual common ground for imitative interaction with others (Moore and D'Entremot, 2001; Tomasello, 2000). Imitation is, from mimicry, a dynamic process, involving accurate and precise timing essential for reciprocal interactions which can take the form of cooperative games in which a child spatially and temporally coordinates his or her actions with a partner. Nadel-Brulfert and Baudonnière (1982) and Nadel (2011) highlight synchronous imitation between peers, initiated by mimicry during the pre-linguistic period, as a significant hallmark in the development of a child's communication skills. Further, Wallon (1956) writes on the subject of imitative play during early development, noting the profound sociability of childhood, a time during which emotion and its sharing appear as the first means of interpersonal communication. He argues that these interactive exchanges allow partners to individually overcome a state of specular confusion "in which the identity of the ego vacillates with that of the alter ego."

This apparent lack of self-other distinction thus leads to relative uncertainty regarding the personal location of the experience. It is interesting to note the link between this stage of child development and autoscopic phenomena, heautoscopy (i.e., the encounter with an alter ego) in particular, described in pathological conditions such as hallucinations (Brugger, 2002). Further, imitative movements can gradually lead to role reversal and reciprocity, whereby each partner is able to identify his or her own purpose and intentions.

These reciprocal imitative interactions reveal a playful dynamic, involving repetition and perspective taking, driven by continuous position reversals which challenge the visuospatial abilities of its partners (Xavier et al., 2013). They require temporal adaptation with unintentional interpersonal motor synchronization (Fogel, 1993; Ikegami and Iizuka, 2007; Wilson, 2005) rooted in rhythmic coordination between individuals. This mutual adjustment also requires flexibility and fluidity, with alternating periods of continuity-discontinuity and engagement-disengagement.

3. Interactional synchrony: From the experience of similarity to the connection of minds

Interpersonal coordination is typically defined as "the degree to which the behaviors in an interaction are nonrandom, patterned, or synchronized in both timing and form [simultaneous movements or change of postures]" (e.g., Hove and Risen, 2009; Lakens, 2010). Interpersonal coordination is often divided in two fundamental components: behavior matching (i.e., similarity) and interactional synchrony (Bernieri and Rosenthal, 1991). Behavior matching is largely related to imitation, while interactional synchrony refers, more specifically, to the adaptation of an individual to the rhythms and movements of an interaction partner (Condon and Ogston, 1967) and the degree of congruence between the behavioral cycles of engagement and disengagement of the two people (Condon and Ogston, 1967; Leclère et al., 2014).

Synchronization has been found to be a stable pattern in human behavior (Richardson et al., 2005, 2007; Schmidt et al., 1990; van Ulzen et al., 2008) and an important precursor to prosocial behavior (Leclère et al., 2014). It has been shown to foster cooperation (Valdesolo et al., 2010), enhance perceptual sensitivity toward others, and lead to a more positive perception of the interaction partner (Miles et al., 2010; Valdesolo et al., 2010; Kokal et al., 2011).

In addition, synchrony plays a major role in the development of affective regulation, social understanding, and empathy (Feldman, 2007a; Semin, 2007). From birth, children are motivated to synchronously, and intersubjectively, engage in rhythmic actions with others (Trevarthen, 1998, 2004, 2011, 2012). Interactional synchrony is critical to infant–mother relationships and, as an early-learned life experience, has been associated with improved communication and prosocial behavior in typically developing children (Siller and Sigman, 2002; Saint-Georges et al., 2013a; Cirelli et al., in press). Mimicry, establishing a relationship by means of similarity (Singer and Lamm, 2009), is related to the concept that others are "like me," which, according to Meltzoff (2005), is "the bedrock on which social cognition is built." Further, during childhood and adolescence, synchrony appears as a social prerequisite for the successful achievement of collaborative goals and the establishment of friendship (Hove and Risen, 2009; Wiltermuth and Heath, 2009; Tunçgenç et al., 2015).

Several studies, mostly performed in adults, have shown that the increase in communication, compassion, and altruistic behavior during interpersonal synchrony may be the result of an experience of self-other merging (e.g., Valdesolo and DeSteno, 2011; Kokal et al., 2009; Wiltermuth and Heath, 2009). Rabinowitch and Knafo-Noam et al. (2015) demonstrated that three minutes of synchronous tapping was sufficient to positively alter the senses of similarity and closeness between children. Therefore, social synchrony may function as a sign of interpersonal similarity, which could allow individuals, for at least a brief period of time, to perceive themselves in unity (Marsh et al., 2009; Lakens, 2010). In fact, this experience of similarity, which allows "simultaneous partial mutual access to internal states" (Semin, 2007), has been thought to be the first step toward the understanding of others' intentions and emotions (Feldman, 2007b; Chaby et al., 2012; Tunçgenç et al., 2015).

This hypothesis has even been supported on a molecular level by empirical research in the field of neuroscience. For example, oxytocin (OT), a neuropeptide synthesized in the hypothalamus, has been implicated in complex socio-cognitive behavior, such as imitation, affiliation, and parenting (for review, Feldman et al., 2015). Additionally, intranasal OT administration in humans has been shown to enhance social information processing abilities (e.g., facial emotion recognition) see Graustella and MacLeod (2012) and, more specifically, repetitive, rhythmic, and synchronous behaviors required for cooperation (De Dreu et al., 2010; Arueti et al., 2013; Feldman et al., 2015). Specifically, one study found that during father – infant synchronous exchanges, OT administration to the father increased both father's and infant's social behaviors (Weisman et al., 2012), which appeared to be shaped by father's affectionate touch and motionese (Weisman et al., 2013).

Despite this biochemical insight, relatively little is known about the neural mechanisms underlying interactional synchrony. The first neurophysiological evidence demonstrating changes in infant neural responses when observing others came from EEG studies on the mu rhythm band oscillations (8–13 Hz), showing mu attenuation during both action observation and execution (for review see, Marshall and Meltzoff, 2011, 2014). Then, inspired by the discovery of mirror neurons in macaque monkeys (Gallese et al., 1996), fMRI studies revealed the existence of an imitative brain network in humans that involved the superior temporal sulcus and fronto-parietal regions (Iacoboni et al., 1999; for review, see Iacoboni, 2005). More recently, EEG hyperscanning methods have been used to simultaneously record brain activity from two partners in different social contexts and determine the means by which co-variation in their neural activity relates to their behavioral interactions. In adults, EEG synchronization between two brains has been found in the alpha–mu frequency bands (8–13 Hz) when individuals are engaged in synchronized action (e.g., imitation of hand movements) (Dumas et al., 2010; Yun et al., 2012) or more spontaneous social interaction (Delaherche et al., 2014). Synchrony has also been found in the mirror neuron network, particularly in the anterior cingular cortex (ACC), of the brains of parents in response to videos depicting their own children but not to unfamiliar children (Atzil et al., 2014).

Given this extant literature, it is clear that, as a dynamic phenomenon, the detection and evaluation of synchrony in interpersonal contexts is critical to understanding the fundamentals of social interaction. However, attempts to quantitatively assess interactional synchrony have been largely limited to the manual coding of movies (Leclère et al., 2014). On a global level, synchrony has been studied through parent-infant interactions by means of interaction and synchrony scales (see Leclère et al., 2014) and video annotation software (e.g. Anvil software; Grynszpan et al., 2003). From this research, three parameters have emerged as key markers of synchrony: the degree of synchrony (i.e., the degree of matching accuracy between the partners), the lead-lad synchrony (i.e., who is driving the interaction) and the time-lag synchrony (i.e., the temporal delay between changes in one partner's behavior and parallel changes in the other's) (Feldman, 2007b; Delaherche et al., 2012).

Of late, interactional synchrony has captured the interest of researchers in the field of social signal processing (SSP) and social robotics (see Chetouani, 2014). Computational methods have been developed to record metrics (called "social signatures") during human–human or human–robot interactions. Given that interactional synchrony involves multimodal signals (e.g., vocalizations, smiles, gestures; see Chaby et al., 2012) produced more or less simultaneously, parent–infant interactions have been analyzed through global computational methods (e.g., non-negative matrix factorization; see Delaherche et al., 2012) to decompose behaviors in short temporal windows and quantify social interactions.

These methods have been proven to be valuable in the differential diagnosis of autism spectrum disorders (ASD) and other intellectual disabilities (Saint-Georges et al., 2013b). They have also been used to distinguish, based on motor activity, mother-infant dyads with and without maternal neglect during free play early interaction (Leclère et al., 2016; Avril et al., 2014). In a study of human–robot interaction, a robot was programmed to produce a random posture, which a participant was subsequently instructed to imitate. By using a specific computational architecture, the robot was able to learn by imitation. After a short period of interaction, by the same token, when the participant produced a posture, the robot would mimic him or her. Adults, typically developing (TD) children, and children with ASD were recruited for participation in the study and a "social signature" was generated for each participant based on the number of neurons required by the robot to learn by imitation (Boucenna et al., 2014). Results indicated that the robot recognized and learned the postures of adults more easily than those of children (both TD children and children with ASD), thus indicating a developmental age effect. Additionally, the robot had more difficulties (i.e., more neurons were recruited) learning the postures of children with ASD (compared to TD children) due to their highly variable movement. Interestingly, the robot was able to detect subtle instabilities in the children's posture (i.e., in the spatial and temporal micro-stability) that went undetected by the therapist's manual coding of the video. Thus, these computational methods offer an interesting and promising approach to the modeling of typical and pathological developmental trajectories of motor imitation.

4. Interpersonal rhythmic coordination in the development of empathy

Motor imitation is a shared experience and prerequisite for the understanding of others' emotions and intentions (Meltzoff and Decety, 2003; Decety and Meyer, 2008). Thus, it has been suggested that imitative exchanges, derived from mimicry, could underlie the development of theory of mind (TOM) and empathy in children (Meltzoff and Decety, 2003). In the field of social cognition, the concept of TOM designates the cognitive processes that allow the representation and understanding of one's own states of mind (e.g., faiths, desires, intentions) and those of others as well as the ability to predict one's actions (Xavier et al., 2013). In contrast, empathy refers to several distinct processes that include emotional sharing and the cognitive ability to recognize others as intentional beings. As a corollary, it also requires the ability to differentiate one's own experience from that of others (Decety and Meyer, 2008), which itself necessitates a sense of self-awareness (Stern, 1989).

Empathy is grounded in emotional contagion, defined as "the tendency to automatically mimic and synchronize facial expressions, vocalizations, postures, and movements with those of another person" (Hatfield et al., 1994). Consequently, people "catch the emotions" of others as a result of afferent feedback generated by elementary motor mimicry of others' expressions. The cognitive dimension of empathy, relates to processes involved in TOM, emotion regulation, and executive functions (i.e. the processes that serve to monitor and control thought and actions, including planning, cognitive flexibility, response inhibition, and resistance to interference) (Decety, 2010). It is underscored by to the ability to consciously simulate the subjective experience of others. Through imitation, TOM arises along with the ability to understand others' emotions, maintain conversations, develop social grace, lie, and recognize when someone is lying (Gonzalez-Liencres et al., 2013).

We argue that rhythmic interpersonal coordination during imitative exchanges contributes invaluably to the development of empathy. Xavier et al. (2013) proposed a developmental model in which empathy is conceptualized through peer interactions during childhood. As described previously (see Part 2), from a developmental perspective, motor imitation is a shared experience, leading to an embodied representation of another's emotional state. It challenges the visuospatial abilities of the child. These abilities are involved in the definition of empathy offered by Berthoz (2004): the author proposes an original model in which he highlights the spatial dimension of empathy which corresponds to the "acquisition of the capacity to manipulate space by changing reference table (from ego to allocentric)" and finally to the ability to integrate the experience of others into one's own perspective.

Empathy, which includes an emotional (EC) and a cognitive component (CC), as well as the self-other distinction (SOD), could be viewed as the product of the spatial and temporal aspects of spontaneous imitation. It should be stated that these two dimensions should not be considered independently, because it is by using visuospatial abilities that children can enroll synchronously in the interaction. Interpersonal synchrony offers an experience of merging, of similarity, corresponding to the emotional resonance at the base of the EC.

Given that imitation is not the production of an exact copy of another's posture or behavior, but rather to produce a similar version in which a part of oneself, albeit insufficiently individualized, is inevitably present, each partner will gradually experiment with a certain degree of self- / non-self-distinction, i.e. gradually draw a distinction between their own movements, gestures, and intentions from those of others. In addition, this differentiation is fostered by the vacillating rhythmic cycles of engagement and disengagement between the interaction partners. As such, we argue that the imitative experience, involving rhythmic variations and requiring continuous adaptation between partners, with shifts between ego- and hetero-centered perspectives, may participate in the development of executive functions (as above defined). On this subject, Frick and Baumeler (2017) found a significant correlation between perspective-taking and inhibitory control, a key aspect of executive functions, both abilities showing developmental progression into childhood (Davidson et al., 2006). In addition, on the neuro-functional level, notwithstanding the structural heterogeneity of the various sub-regions of the medial prefrontal cortex, one can emphasize both the importance of its role in the development of executive functions and in thinking about others as "like me" as well as third-person perspective taking.

It is in this way that the SOD, corresponding to the "self–other control," (i.e., the ability to manipulate the extent to which self- or other-relevant representations are activated during an interaction) (De Guzman et al., 2015) and the CC, with the sense of agency and perspective taking as well as the ability to integrate perspectives could relate, according to the developmental perspective described by Wallon, to the finality of this imitative process.

Interestingly, in the continuity of the human-robot interaction experience related above (Boucenna et al., 2014), the same group used another computational model with robot implementation to explore the functional value of action imitation. They showed in three different experiments using a mutual imitation task that the robot was able to learn from an interactive experience involving mutual imitation. This mutual imitation experience allowed the robot to recognize the interactive agent in a subsequent encounter. These experiments using robots as tools for modeling human cognitive development illustrate how person recognition may emerge through imitative experience and intercorporeal mapping (Boucenna et al., 2016).

In order to illustrate our idea we address, in the last chapter, a motor disorder characterized by coordination impairments, which have a negative impact, at a social and emotional level, on the child's imitation capacities.

5. Rhythmic coordination impairments in developmental coordination disorder (DCD)

Developmental Coordination Disorder (DCD), as described in the *DSM-5* (American Psychiatric Association, 2013), is a neurodevelopmental condition characterized by impaired coordination and motor control. Often described as "clumsy" or "awkward," children with

DCD have difficulties performing simple tasks involving coordinated movement, (e.g., skipping, tying shoes, writing, using scissors) as well as more advanced behaviors (e.g., imitation) (Volman and Geuze, 1998). Their "clumsiness" often poses difficulties in academic performance and their ability to care for themselves. Underlying these motor difficulties are visuo-spatial oculomotor and gaze processing deficits and the inability to execute fluid, volitional movement (Mazeau, 2010; Sigmundsson et al., 2003). Because of this lack of automation, the gestures of children with DCD remain locked under attentional control without an effective means of intentional motor expression, resulting in jerky bodily motion, irregular gait, increased fatigability, and lethargy (van der Linde et al., 2015; Crespo-Eguílaz et al., 2014).

Deficits in rhythmic intrapersonal coordination have also been well established in DCD (Vaivre-Douret et al., 2011), namely the inability to intrinsically couple sensory input to desirable motor execution in fixed temporal succession (Mackenzie et al., 2008; Volman and Geuze, 1998). Using an information processing approach to motor control, several studies have discovered significant discontinuity in the rhythmic movements (e.g., tapping, clapping, marching) of children with DCD in response to external stimuli (e.g., De Castelnau et al., 2007; Lord and Hulme, 1987; Volman and Geuze, 1998; Whitall et al., 2006). This discontinuity has largely been attributed to the impaired visual-motor, kinesthetic-motor, and auditorymotor capacities associated with the condition (Mackenzie et al., 2008; Volman and Geuze, 1998; Wilson and McKenzie, 1998). It is still unknown, however, whether these performance difficulties are due to a fundamental inability to coordinate sustained rhythmic motion or, rather, to deficits in the sensory processing of stimuli and subsequent relay mechanisms manifesting as expressive motor impairment (Mackenzie et al., 2008; Whitall et al., 2006). Regardless, it is clear that children with DCD lack the temporal coordination of typically developing children, which largely precludes them from achieving sustained patterns of rhythmic behavior (Volman and Geuze, 1998).

DCD has also been associated with significant multisensory deficits in behavioral synchronization (Kelso, 1995; Wilson et al., 2012). Wing and Kristofferson (1973) were among the first to show that, in a task involving motor synchronization with an auditory stimulus, children with DCD expressed greater variability in their performance than did TD controls. This inability to achieve consistent auditory-motor synchronization has since been strongly supported in the literature (e.g., Engström et al., 1996; Whitall et al., 2008; Williams et al., 1992; Wilson et al., 2012). In another study on visuoperception, children with DCD had more difficulties with a visual tracking task that involved synchronization of their eye movements with a moving object (Langaas et al., 1998). Volman and Geuze (1998) similarly reported poorer synchronization between finger movements and a visual stimulus in DCD. Taken together, it is clear that several aspects of dynamic pattern stability and synchronous behavior are markedly deficient in children with DCD (De Castelnau et al., 2007; Wilson et al., 2012).

Beyond its impact on coordination, DCD may have a significant impact on the global functioning of children, including deficits in learning and social interaction (Jokic and Whitebread, 2011; Mazeau, 2010). DCD has been shown to damage peer relationships (Poulsen et al., 2008; Smyth and Anderson, 2000) and has been linked to exclusion, social ostracism, and bullying (Cermak and Larkin, 2002; Wagner et al., 2012). Cummins et al. (2005) attributes these social and emotional difficulties to fundamental deficits in the development of empathy. As a result, psychosocial comorbidities, such as low self-esteem, anxiety, and depression, are commonly reported in children with DCD (Campbell et al., 2012; Green et al., 2006; Schoemaker and Kalverboer, 1994).

All in all, it is clear the behavioral impairments found in children with DCD (Green et al., 2006) are the consequence of a combination of inabilities concerning (1) visuospatial processing and (2) the calibration of sensorimotor information in an interpersonal synchrony.

In accordance with the previously described theories on the interdependent relationship between imitation, rhythmic interpersonal coordination, motor synchrony, and the development of empathy, the imitative impairments in children with DCD could, at least partially, explain their emotional and socio-interactional difficulties.

Their deficits concerning (1) would influence perception–action coupling of emotional expression (Decety and Meyer, 2008). According to (2), children with DCD may, from very early in life, be unable to react contingently to others' emotional expressions (Trevarthen and Aitken, 2001), and therefore, through impaired mimicry, to resonate emotionally with others. This disynchronization experienced in their relationships with caregivers and peers could therefore, in the most severe cases, have a negative impact on the development of social cognitive abilities (i.e., TOM) and on their capacity to empathize.

6. Conclusion

In this paper, we sought to examine imitative motor exchanges between children and their peers from the perspective of rhythmic behavior, specifically synchrony. Through our review of the literature and the consideration of this form of communication in a pathological framework, in children with DCD, we tried to highlight the critical role that motor imitation plays in the intersubjective development of higher-level cognitive processes, such as TOM and empathy. This evidence challenges the traditionally-held assumption in cognitive psychology that such developmental processes can be sufficiently understood through the study of individual minds in isolation. It is now clear that investigating cognition through imitative peer interaction offers a unique and novel perspective on this subject. However, exploring this dynamic process from a developmental point of view, in which both visual-spatial and rhythmic aspects are considered in terms of perspective taking and synchrony, poses significant pragmatic challenges for researchers and clinicians alike. In this regard, an approach using methods borrowed from the field of social signal processing (SSP) and social robotics may be promising (Meltzoff et al., 2009).

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References

American Psychiatric Association, 2013. Diagnostic and Statistical Manual of Mental Disorders. American Psychiatric Publishing, Arlington, VA.
Arueti, M., Perach-Barzilay, N., Tsoory, M.M., Berger, B., Getter, N., Shamay-Tsoory, S.G., 2013. When two become one: the role of oxytocin in interpersonal coordination and cooperation. J. Cognit. Neurosci. 25 (9), 1418–1427.
Atzil, S., Hendler, T., Feldman, R., 2014. The brain basis of social synchrony. Soc. Cognit. Affect. Neurosci. 9 (8), 1193–1202.
Avril, M., Leclère, C., Viaux, S., Michelet, S., Achard, C., Missonnier, S., Keren, M., Cohen, D., Chetouani, M., 2014. Social signal processing for studying parent-infant interaction. Front. Psychol. 5, e1437.
Bernieri, F., Rosenthal, R., 1991. Interpersonal coordination: behavior matching and interactional synchrony. In: Fundament. Nonverb. Behav.. Cambridge Univ. Press..
Berthoz, A., 2004. Physiologie du changement de point de vue. In: Berthoz, A., Jorland, G. (Eds.), L'empathie. Editions Odile Jacob, Paris, pp. 251–275.
Blakemore, S., Frith, C., 2003. Self-awareness and action. Curr. Opin. Neurobiol. 4, 219–224.
Boucenna, S., Anzalone, S., Tilmont, E., Cohen, D., Chetouani, M., 2014. Learning of social signatures through imitation game between a robot and a human partner. IEEE Trans.Autonom. Mental Develop. 6 (3), 213–225.
Boucenna, S., Cohen, D., Meltzoff, A., Gaussier, P., Chetouani, M., 2016. Cognitive developmental robotics: How robots learn to recognize individuals from imitating children with autism and other agents. Scientific Report 6, 19908. doi: http://dx.doi.org/10.1038/srep19908.
Brugger, P., 2002. Reflective mirrors: perspective-taking in autoscopic phenomena. Cognitive Neuropsychiatry 7 (3), 179–194. http://dx.doi.org/10.1080/13546800244000076.
Campbell, W.N., Missiuna, C., Vaillancourt, T., 2012. Peer victimization and depression in children with and without motor coordination difficulties. Psychol. Sch. 49, 328–341. http://dx.doi.org/10.1002/pits.21600.
Carpenter, M., Nielsen, M., 2008. Tools, TV, and trust: introduction to the special issue on imitation in typically-developing children. J. Exp. Child Psychol. 101, 225–227.
Cermak, S.A., Larkin, D., 2002. Chapter XIII. Families as partners, in: Developmental Coordination Disorder. Cengage Learning, pp. 200-208
Chaby, L., Chetouani, M., Plaza, M., Cohen, D., 2012. Exploring multimodal socialemotional behaviors in autism spectrum disorders: an interface between social signal processing and psychopathology. SocialCom/PASSAT, 950–954.
Chetouani, M., 2014. Role of inter-personal synchrony in extracting social signatures: some case studies. In: Proceedings of the 2014 Workshop on Roadmapping the Future of Multimodal Interaction Research including Business Opportunities and Challenges, ACM, pp. 9–12.
Cirelli, L., Einarson, K., Trainor, L. in press. Interpersonal synchrony increases prosocial behavior in infants. Dev. Sci. doi: http://dx.doi.org/10.1111/desc.12193.
Condon, W., Ogston, W., 1967. A segmentation of behavior. J. Psychiatr. Res. 5, 221–235.
Crespo-Eguílaz, N., Magallón, S., Narbona, J., 2014. Procedural skills and neurobehavioral freedom. Front. Hum. Neurosci. 8, 449. http://dx.doi.org/10.3389/fnhum.2014.00449.

Cummins, A., Piek, J.P., Dyck, M.J., 2005. Motor coordination, empathy, and social behaviour in school-aged children. Dev. Med. Child Neurol. 47, 437–442. http://dx.doi.org/10.1111/j.1469-8749.2005.tb01168.x.
Davidson, M.C., Amso, D., Anderson, L.C., Diamond, A., 2006. Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. Neuropsychologia 44, 2037–2078.
De Castelnau, P., Albaret, J.-M., Chaix, Y., Zanone, P.G., 2007. Developmental coordination disorder pertains to a deficit in perceptuo-motor synchronization independent of attentional capacities. Hum. Mov. Sci. 26, 477–490.
Decety, J., 2010. The neurodevelopment of empathy in humans. Dev. Neurosci. 32 (4), 257–267. http://dx.doi.org/10.1159/000317771.
Decety, J., Meyer, M., 2008. From Emotion Resonance to Empathic Understanding: A Social Developmental Neuroscience Account 20, 1053–1080. http://dx.doi.org/10.1017/S0954579408000503.
De Dreu, C.K.W., Greer, L.L., Handgraaf, M.J., Shalvi, S., Van Kleef, G.A., Baas, M., Ten Velden, F.S., Van Dijk, E., Feith, S.W., 2010. The neuropeptide oxytocin regulates parochial altruism in intergroup conflict among humans. Science 328, 1408–1411.
De Guzman, M., Bird, G., Banissy, M.J., Catmur, C., 2015. Self-other control processes in social cognition: from imitation to empathy. Philos. Trans. Roy. Soc. B Biol. Sci. http://dx.doi.org/10.1098/rstb.2015.0079.
Delaherche, E., Chetouani, M., Mahdhaoui, A., Saint-Georges, C., Viaux, S., Cohen, D., 2012. Interpersonal synchrony: a survey of evaluation methods across disciplines. IEEE Trans. Affect. Comput. 3 (3), 349–365.
Delaherche, E., Dumas, G., Nadel, J., Chetouani, M., 2014. Automatic measure of imitation during social interaction: a behavioral and hyperscanning-EEG benchmark. Pattern Recogn. Lett.
Dumas, G., Nadel, J., Soussignan, R., Martinerie, J., Garnero, L., 2010. Inter-brain synchronization during social interaction. PLoS One 5 (8), e12166.
Engström, D.A., Kelso, J.A.S., Holroyd, T., 1996. Reaction–anticipation transitions in human perception–action patterns. Hum. Mov. Sci. 15, 809–832.
Feldman, R., 2007a. Mother-infant synchrony and the development of moral orientation in childhood and adolescence: direct and indirect mechanisms of developmental continuity. Am. J. Orthopsychiatry 77 (4), 582–597.
Feldman, R., 2007b. Parent-infant synchrony and the construction of shared timing; physiological precursors, developmental outcomes, and risk conditions. J. Child Psychol. Psychiatry 48 (3–4), 329–354.
Feldman, R., Monakhov, M., Pratt, M., Ebstein, R.P., 2015. Oxytocin pathway genes: evolutionary ancient system impacting on human affiliation, sociality, and psychopathology. Biol. Psychiat. 79 (3), 174–184. http://dx.doi.org/10.1016/j.biopsych.2015.08.008.
Fogel, A., 1993. Two principles of communication: co-regulation and framing. New Perspectives in Early Communicative Development, Series Int'l Library of Psychology, Routledge. <http://books.google.fr/books?id=mXYOAAAAQAAJ>.
Frick, A., Baumeler, D., 2017. The relation between spatial perspective taking and inhibitory control in 6-year-old children. Psychol. Res. 81 (4), 730–739. http://dx.doi.org/10.1007/s00426-016-0785-y.
Gallagher, S., Meltzoff, A.N., 1996. The earliest sense of self and others: Merleau-Ponty and recent developmental studies. Philos. Psychol. 9, 211–233. http://dx.doi.org/10.1080/09515089608573181.
Gallagher, S., 2001. The practice of mind: theory, simulation, or interaction? J. Conscious. Stud. 8 (5-7), 83–108. Available at http://pegasus.cc. ucf.edu/~gallaghr/practice01.htm.
Gallagher, S., 2004. Hermeneutics and the cognitive sciences. J. Consciousness Stud. 11, 10–11.
Gallese, V., Fadiga, L., Fogassi, L., Rizzolatti, G., 1996. Action recognition in the premotor cortex. Brain 119, 593–609.
Gergely, G., Koos, O., Watson, J.S., 2002. Perception causale et rôle des comportements imitatifs des parents. In: Nadel, J., Decety, J. (Eds.), Imiter Pour Découvrir l'humain, Paris, Puf.
Gonzalez-Liencres, C., Shamay-Tsoory, S.G., Brüne, M., 2013. Towards a neuroscience of empathy: ontogeny, phylogeny, brain mechanisms, context and psychopathology. Neurosci. Biobehav. Rev. 37 (8), 1537–1548. http://dx.doi.org/10.1016/j.neubiorev.2013.05.001.
Graustella, A.J., MacLeod, C., 2012. A critical review of the influence of oxytocin nasal spray on social cognition in humans: evidence and future directions. Horm. Behav. 61 (3), 410–418.
Green, D., Baird, G., Sugden, D., 2006. A pilot study of psychopathology in developmental coordination disorder. Child Care Health Dev. 32, 741–750. http://dx.doi.org/10.1111/j.13652214.2006.00684.x.
Grynszpan, O., Martin, J.C., Oudin, N., 2003. On the annotation of gestures in multimodal autistic behaviour. In: The 5th International Workshop on Gesture and Sign Language Based Human-Computer Interaction, pp. 25–33.
Hatfield, E., Cacioppo, J., Rapson, R.L., 1994. Emotional Contagion. Cambridge University Press, New York.
Hove, M.J., Risen, J.L., 2009. It's all in the timing: interpersonal synchrony increases affiliation. Soc. Cognit. 27, 949–961.
Iacoboni, M., Dapretto, M., 2006. The mirror neuron system and the consequences of its dysfunction. Nat. Rev. Neurosci. 7 (12), 942–951.
Iacoboni, M., Woods, R.P., Brass, M., Bekkering, H., Maziotta, J.C., Rizzolatti, G., 1999. Cortical mechanisms of human imitation. Science 286 (5449), 2526–2528.
Iacoboni, M., 2005. Neural mechanisms of imitation. Curr. Opin. Neurobiol. 15 (6), 632–637.
Ikegami, T., Iizuka, H., 2007. Turn-taking interaction as a cooperative and cocreative process. Infant Behav. Develop. 30, 278–288.
Jokic, C.S., Whitebread, D., 2011. The role of self-regulatory and metacognitive competence in the motor performance difficulties of children with developmental coordination disorder: a theoretical and empirical review. Educ. Psychol. Rev. 23, 75–98.
Kelso, J.A.S., 1995. Dynamic Patterns: The Self-Organization of Brain and Behavior. MIT Press, Cambridge, MA.
Kokal, I., Engel, A., Kirschner, S., Keysers, C., 2011. Synchronized drumming enhances activity in the caudate and facilitates prosocial commitment—if the rhythm comes easily. PLoS One 6, e27272. http://dx.doi.org/10.1371/journal.pone.0027272. pmid:22110623.
Lakens, D., 2010. Movement synchrony and perceived entitativity. J. Exp. Soc. Psychol. 46, 701–708.
Lakin, J.L., Chartrand, T.L., 2003. Using nonconscious behavioral mimicry to create affiliation and rapport. Psychol. Sci. 14 (4), 334–339.
Langaas, T., Mon-Williams, M., Wann, J.P., Pascal, E., Thompson, C., 1998. Eye movements, prematurity and developmental co-ordination disorder. Vision. Res. 38, 1817–1826.
Leclère, C., Viaux, S., Avril, M., Achard, C., Chetouani, M., Missonnier, S., Cohen, D., 2014. Why synchrony matters during mother-child interactions: a systematic review. PLoS One 9 (12), e113571.
Leclère, C., Avril, M., Viaux-Savelon, S., Bodeau, N., Achard, C., Missonnier, S., Keren, M., Feldman, R., Chetouani, M., Cohen, D., 2016. Interaction and behaviour imaging: a novel method to measure mother-infant interaction using video 3D reconstruction. Translat. Psychiatry 6, e816. http://dx.doi.org/10.1038/tp.2016.82.
Lord, R., Hulme, C., 1987. Perceptual judgements of normal and clumsy children. Dev. Med. Child Neurol. 29, 250–257.
Mackenzie, S.J., Getchell, N., Deutsch, K., Wilms-Floet, A., Clark, J.E., Whitall, J., 2008. Multi-limb coordination and rhythmic variability under varying sensory availability conditions in children with DCD. Hum. Mov. Sci. 27, 256–269.
Marsh, K.L., Richardson, M.J., Schmidt, R.C., 2009. Social connection through joint action and interpersonal coordination. Top. Cognit. Sci. 1, 320–339.
Marshall, P.J., Meltzoff, A.N., 2011. Neural mirroring systems: exploring the EEG mu rhythm in human infancy. Develop. Cognit. Neurosci. 1 (2), 110–123.
Marshall, P.J., Meltzoff, A.N., 2014. Neural mirroring mechanisms and imitation in human infants. Philos. Trans. Roy. Soc. B Biolog. Sci. 369 (1644), 20130620.
Mazeau, M., 2010. Les dyspraxies: points de repères. Arch. Pédiatrie 17, 314–318. http://dx.doi.org/10.1016/j.arcped.2009.10.016.
Meltzoff, a.N., Decety, J., 2003. What imitation tells us about social cognition: a rapprochement between developmental psychology and cognitive neuroscience. Philos. Trans. Roy. Soc. B Biol. Sci. 358 (1431), 491–500. http://dx.doi.org/10.1098/rstb.2002.1261.
Meltzoff, A., 2005. Imitation and other minds: The "like me" hypothesis. In: Hurley, S., Chater, N. (Eds.), Perspectives on Imitation: From Neuroscience to Social Science, vol. 2. MIT Press, Cambridge, MA, pp. 55–77.
Meltzoff, A.N., Kuhl, P.K., Movellan, J., Sejnowski, T.J., 2009. Foundations for a new science of learning. Science 325, 284–288.
Meltzoff, A.N., Moore, M.K., 1977. Imitation of facial and manual gestures by human neonates. Science 198, 75–78.
Meltzoff, A.N., 1990. Foundations for developing a concept of self: The role of imitation in relating self to other and the value of social mirroring, social modelling, and self-practice in infancy. In: Cicchetti, D., Beeghly, M. (Eds.), 1995. The Self in Transition, Chicago: University of Chicago Press, pp. 139–164. Understanding the Intentions Mothers: Re-enactment of Intended Acts by 18-month-old Children. Developmental Psychology, vol. 31, pp. 838–850.
Meltzoff, A.N., Gopnik, A., 1993. The role of imitation in understanding persons and developing a theory of mind. In: Baron-Cohen, S., Tager- Flusberg, H., Cohen, D.J. (Eds.), Understanding Other Minds: Perspectives From Autism. Oxford University Press, New York, pp. 335–366.
Miles, L.K., Nind, L.K., Henderson, Z., Macrae, C.N., 2010. Moving memories: behavioral synchrony and memory for self and others. J. Exp. Soc. Psychol. 46, 457–460. http://dx.doi.org/10.1016/j.jesp.2009.12.006.
Moore, C., D'Entremot, B., 2001. Developmental changes in pointing as a function of attentional focus. J. Cogn. Dev. 2 (109–129), 9.
Nadel, J., 2011. Imiter pour grandir. Développement du bébé et de l'enfant avec autisme. Dunod, Paris.
Nadel, J., Potier, C., 2002. Imiter et être imité dans le développement de l'intentionnalité. In: Nadel, J., Decety, J. (Eds.). Imiter pour découvrir l'humain, PUF, pp. 83–104.
Nadel-Brulfert, J., Baudonnière, P.M., 1982. The social function of reciprocal imitation in 2year-old peers. Int. J. Behav. Dev. 5, 95–109.
Niedenthal, P.M., 2007. Embodying emotion. Science 316, 1002–1005.
Poulsen, A.A., Ziviani, J.M., Johnson, H., Cuskelly, M., 2008. Loneliness and life satisfaction of boys with developmental coordination disorder: the impact of leisure participation and perceived freedom in leisure. Hum. Mov. Sci. 27, 325–343. http://dx.doi.org/10.1016/j.humov.2008.02.004.
Rabinowitch, T.C., Knafo-Noam, A., 2015. Synchronous rhythmic interaction enhances children's perceived similarity and closeness towards each other. PLoS One 10 (4), e0120878. http://dx.doi.org/10.1371/journal.pone.0120878.
Richardson, M.J., Marsh, K.L., Schmidt, R.C., 2005. Effects of visual and verbal interaction on unintentional interpersonal coordination. J. Exp. Psychol. Hum. Percept. Perform. 31 (1), 62–79. ISSN 0096-1523.
Richardson, M.J., Marsh, K.L., Isenhower, R.W., Goodman, Justin, R.L., Schmidt, R.C., 2007. Rocking together: dynamics of intentional and unintentional interpersonal coordination. Hum. Mov. Sci. 26 (6), 867–891. ISSN 0167–9457.
Rizzolatti, G., Fadiga, L., Gallese, V., Fogassi, L., 1996. Premotor cortex and the recognition of motor actions. Cognit. Brain Res. 3 (2), 131–141.

Rogers, S.J., Cook, I., Meryl, A., 2005. Imitation and play in autism. In: Volkmar, F.R., Saint-Georges, C., Cassel, R. S., Cohen, D., Chetouani, M., Laznik, M.C., Maestro, S., Muratori, F., 2010. What Studies of Family Home Movies Can Teach us About Autistic Infants: A Literature Review. Research in Autism Spectrum Disorders, vol. 4, no. 3, pp. 355–366.
Saint-Georges, C., Chetouani, M., Cassel, R., Apicella, F., Mahdhaoui, A., Muratori, F., Laznik, M.-C., Cohen, D., 2013a. Motherese in interaction: At the cross-road of emotion and cognition? (A Systematic Review). PLoS One 8 (10), e78103. http://dx.doi.org/10.1371/journal.pone.0078103.
Saint-Georges, C., Guinchat, V., Chamak, B., Apicella, F., Muratori, F., Cohen, D., 2013b. Signes précoces d'autisme: d'où vient-on? Où va-t-on? Neuropsychiatrie l'Enfance et l'Adolescence 61 (7), 400–408.
Schmidt, R.C., Carello, C., Turvey, M.T., 1990. Phase transitions and critical fluctuations in thevisual coordination of rhythmic movements between people. J. Exp. Psychol. Hum. Percept. Perform. 16, 227–247.
Schoemaker, M.M., Kalverboer, A.F., 1994. Social and affective problems of children who are clumsy: how early do they begin ? Adapt. Phys. Act. Q. 11 (2), 130–140.
Semin, G.R., 2007. Grounding communication: synchrony. In: Kruglanski, A.W., Higgins, E.T. (Eds.), Social Psychology: Handbook of Basic Principles. second ed. The Guilford Press, New York, NY, pp. 630–649.
Sigmundsson, H., Hansen, P.C., Talcott, J.-B., 2003. Do "clumsy" children have visual deficits ? Behav. Brain Res. 139, 123–129.
Siller, M., Sigman, M., 2002. The behaviors of parents of children with autism predict the subsequent development of their children's communication. J. Autism Dev. Disord. 32, 77–89.
Singer, T., Lamm, C., 2009. The social neuroscience of empathy. Ann. N. Y. Acad. Sci. 1156, 81–96.
Stern, D.N., 1989. Le sens d'un soi émergeant. In: Le monde interpersonnel du nourrisson, PUF, pp. 57–95.
Smyth, M.M., Anderson, H.I., 2000. Coping with clumsiness in the school playground: social and physical play in children with coordination impairments. Br. J. Dev. Psychol. 18, 389–413. http://dx.doi.org/10.1348/026151000165760.
Tomasello, M., 2000. Culture and cognitive development. Curr. Dir. Psychol. Sci. 9, 37–40.
Trevarthen, C., 1998. The concept and foundations of infant intersubjectivity. In: Bråten, S. (Ed.), Intersubjective Communication and Emotion in Early Ontogeny. Cambridge University Press, Cambridge, pp. 15–46.
Trevarthen, C., 2004. La communication de l'expérience par l'intersubjectivité : comment les bébés saisissent le sens de nos actions et de nos paroles. Psychiatrie Française 35 (2), 8–44.
Trevarthen, C., 2011. What is it like to be a person who knows nothing? Defining the active intersubjective mind of a newborn human being. Infant Child Develop. 20 (1), 119–135.
Trevarthen, C., 2012. Submitted for a Book on "Recherche en Périnatalité" by the WAIMH Francophone Publications.
Trevarthen, C., Aitken, K.J., 2001. Infant intersubjectivity: research, theory, and clinical applications. J. Child Psychol. Psychiatry 42 (1), 3–48.
Tunçgenç, B., Cohen, E., Fawcett, C., 2015. Rock with me: the role of movement synchrony in infants' social and nonsocial choices. Child Dev. 86 (3), 976984.
Vaivre-Douret, L., Lalanne, C., Ingster-Moati, I., Boddaert, N., Cabrol, D., Dufier, J.-L., Falissard, B., 2011. Subtypes of developmental coordination disorder: research on their nature and etiology. Develop. Neuropsychol. 36 (5), 614–643. http://dx.doi.org/10.1080/87565641.2011.560696.
Valdesolo, P., Ouyang, J., DeSteno, D., 2010. The rhythm of joint action: synchrony promotes cooperative ability. J. Exp. Soc. Psychol. 46, 693–695. http://dx.doi.org/10.1016/j.jesp.2010.03.004.
Valdesolo, P., DeSteno, D., 2011. Synchrony and the social tuning of compassion. Emotion, 262–266 [PubMed: 21500895].
Van der Linde, B.W., van Netten, J.J., Otten, E., Postema, K., Geuze, R.H., Schoemaker, M.M., 2015. A systematic review of instruments for assessment of capacity in activities of daily living in children with developmental co-ordination disorder. Child Care Health Dev. 41 (1), 23–34. http://dx.doi.org/10.1111/cch.12124.
Van Ulzen, N.R., Lamoth, C.J.C., Daffertshofer, A., Semin, G.R., Beek, P.J., 2008. Characteristics of instructed and uninstructed interpersonal coordination while walking side-by-side. Neurosci. Lett. 432 (2), 88–93.
Volman, M.J.M., Geuze, R.H., 1998. Stability of rhythmic finger movements in children with a developmental coordination disorder. Mot. Control 2 (1), 34–60. http://dx.doi.org/10.1016/S0167-9457(98)00013-X.
Wagner, M.O., Bös, K., Jascenoka, J., Jekauc, D., Petermann, F., 2012. Peer problems mediate the relationship between developmental coordination disorder and behavioral problems in school-aged children. Res. Dev. Disabil. 33, 2072–2079. http://dx.doi.org/10.1016/j.ridd.2012.05.012.
Wallon, H., 1956. Niveaux et fluctuations du moi. In: Enfance, numéro spécial Henri Wallon, 1959–1963. PUF, Paris, pp. 88–89.
Weisman, O., Zagoory-Sharon, O., Feldman, R., 2012. Intranasal oxytocinadministration is reflected in human saliva. Psychoneuroendocrinology 37, 1582–1586.
Weisman, O., Delaherche, E., Rondeau, M., Chetouani, M., Cohen, D., Feldman, R., 2013. Oxytocin shapes parental motion during father–infant interaction. Biol. Let. 9 (6), 20130828.
Williams, H.G., Woollacott, M.H., Ivry, R., 1992. Timing and motor control in clumsy children. J. Mot. Behav. 24 (2), 165–172.
Whitall, J., Getchell, N., McMenamin, S., Horn, C., Wilms-Floet, A., Clark, J.E., 2006. Perception– action coupling in children with and without DCD: frequency locking between task-relevant auditory signals and motor responses in a dual-motor task. Child Care Health Dev. 32, 679–692.
Whitall, J., Chang, T.Y., Horn, C.L., Jung-Potter, J., McMenamin, S., Wilms-Floet, A., Clark, J.E., 2008. Auditory-motor coupling of bilateral finger tapping in children with and without DCD compared to adults. Hum. Mov. Sci. 27, 914–931 [PubMed: 1863935.
Wilson, P.H., McKenzie, B.E., 1998. Information processing deficits associated with developmental coordination disorder: a meta-analysis of research findings. J. Child Psychol. Psychiatry 39, 829–840.
Wilson, P.H., Ruddock, S., Smits-Engelsman, B., Polatajko, H., Blank, R., 2012. Understanding performance deficits in developmental coordination disorder: a metaanalysis of recent research: Review. Dev. Med. Child Neurol. 55, 217–228. http://dx.doi.org/10.1111/j.1469-8749.2012.04436.x.
Wilson, P.H., 2005. Approaches to assessment and treatment of children with DCD: an evaluative review. J. Child Psychol. Psychiatry 46, 806–823.
Wing, A.M., Kristofferson, A.B., 1973. Respons delays and the timing of discrete motor responses. Percept. Psychophys. 14, 5–12.
Wiltermuth, S.S., Heath, C., 2009. Synchrony and cooperation. Psychol. Sci. 20, 1–5. http://dx.doi.org/10.1111/j.1467-9280.2008.02253.x. pmid : 19152536.
Xavier, J., Tilmont, E., Bonnot, O., 2013. Children's synchrony and rhythmicity in imitation of peers: toward a developmental model of empathy. J. Physiol. Paris 107 (4), 291–297. http://dx.doi.org/10.1016/j.jphysparis.03.012.
Yun, K., Watanabe, K., & Shimojo, S., 2012. Interpersonal Body and Neural Synchronization as a Marker of Implicit Social Interaction. Scientific Reports, 2.