Nonlinear Dynamics, Psychology, and Life Sciences, Vol. 21, No. 2, pp. 189-215.

Cooperative Learning and Interpersonal Synchrony

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Abstract: *Cooperative learning has been shown to result in better task performance, compared to individual and competitive learning, and can lead to positive social effects. However, potential working mechanisms at a micro level remain unexplored. One potential working mechanism might be the level of interpersonal synchrony between cooperating individuals. It has been shown that increased levels of interpersonal synchrony are related to better cognitive performance (e.g., increased memory). Social factors also appear to be affected by the level of interpersonal synchrony, with more interpersonal synchrony leading to increased likeability. In the present study, interpersonal synchrony of postural sway and its relation to task performance and social factors (i.e., popularity, social acceptance, and likeability) was examined. To test this, 183 dyads performed a tangram task while each child stood on a Nintendo Wii Balance Board that recorded their postural sway. The results showed that lower levels of interpersonal synchrony were related to better task performance and those dyads who were on average more popular synchronized more. These results contradict previous findings. It is suggested that for task performance, a more loosely coupled system is better than a synchronized system. In terms of social competence, dyad popularity was associated with more interpersonal synchrony.*

Key Words: cooperative learning, interpersonal synchrony, postural sway, popularity, task performance

INTRODUCTION

From an evolutionary point of view, cooperation is important for human survival (Slavin, 1982). Individuals who are better at cooperating are likely to have better group relations, which would lead to higher chances of survival (de Waal, 1989). Today, the ability to cooperate is still highly valued, as suggested by many existing methods for cooperative learning in schools (Johnson, Johnson, & Stanne, 2000). Over the past few decades a solid theoretical framework has been provided for cooperative learning and its positive effects (Johnson & Johnson, 2009). However, the underlying mechanisms of cooperative learning at a micro-level are largely unexplored. Therefore, the goal of this study was to examine one mechanism that may underlie successful cooperation, namely interpersonal synchrony.

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Cooperative or collaborative learning can take place when two or more individuals work together towards a common goal that can be achieved, for example, through discussion of materials, providing help, mutual encouragement, and checking individual performance regularly (Johnson & Johnson, 1999). In general, cooperative groups outperform individuals and competitive groups (Blaye, Light, Joiner, & Sheldon, 1991; Hooper, 1992; Hooper, Temiyakarn, & Williams, 1993; Johnson & Johnson, 1999; Johnson, Johnson, & Skon, 1979; Johnson, Maruyama, Johnson, Nelson, & Skon, 1981; Roseth, Johnson, & Johnson, 2008).

There is ample theoretical support for the positive effects of cooperative learning on academic and social outcomes (Johnson & Johnson, 2009). Cognitive-developmental theories, for example that of Piaget (1959), focus on the importance of elaboration and verbalization as well as the process of peer modeling (Abrami & Chambers, 1996). A more recent theory of cooperative learning is social interdependence theory, which focuses on the social factors that affect cooperation (Johnson & Johnson, 2009).

Cooperative Learning Theories

Piaget (1959) stated that cognitive development requires active interaction with the environment, usually including other children of similar age (Fawcett & Garton, 2005). In interactions with their environment, children encounter situations in which there may be cognitive conflict with peers who have different or opposing viewpoints. Such conflicting opinions can lead to a state of disequilibrium, in which children have to rethink their ideas and consider the information presented by their peer(s). A way to regain a stable state of equilibrium, which all living systems strive for (Piaget, 1959; Strogatz, 2003), is through discussion or dialogue, which in turn may lead to cognitive growth (Fawcett & Garton, 2005). Thus, from a Piagetian point of view, cognitive conflict in and of itself leads to cognitive growth, independent of the ability level of the children involved (Slavin, 1996).

Piaget's theory does not address social correlates of cooperative learning, such as that individuals who care more about one another will work harder to reach a common goal or that increased liking can emerge from cooperative learning (Johnson & Johnson, 1996, 2003). A theory that does address this is social interdependence theory, which focuses on the interdependence between interacting individuals working towards a common goal (Johnson & Johnson, 2009). There are two types of interdependence. Positive interdependence relates to cooperation: Individuals can reach their goals only if they work together with other individuals, which will motivate both to put in the effort necessary to obtain their goals. Negative interdependence refers to competition between individuals, because an individual can only reach her own goals if others do not succeed. A third possibility is no interdependence, in which case the individuals assume that they can reach their individual goals independent of whether others do or do not (Choi, Johnson, & Johnson, 2011).

The type of interdependence is related to the type of interaction between individuals (Choi et al., 2011). When there is positive interdependence, interaction is usually promotive. Individuals encourage one another to maximize their efforts to obtain their common goals. When there is negative interdependence, oppositional interactions are often observed that result from individuals striving for their own goals while preventing others from reaching theirs. Whereas prosocial behavior is observed in promotive interactions, antisocial, or even harmful, behavior can be observed in oppositional interactions. When there is no interdependence there will be no interaction. Thus, the type of goals and the accompanying interactions are (in part) determined by the social dependencies between individuals.

Together, these theoretical perspectives provide a solid foundation for the assumption that cooperative learning can positively affect cognition (Piaget, 1959) and that social factors are also related (Choi et al., 2011; Johnson & Johnson, 1996). Apart from this theoretical foundation, a large number of studies over the last several decades have provided substantial evidence for the positive effects of cooperative learning (Underwood, McCaffrey, & Underwood, 1990; van Boxtel, van der Linden, & Kanselaar, 2000; Yager, Johnson, & Johnson, 1985).

Correlates of Cooperative Learning

Many studies across differing fields of research have provided evidence for the increased performance of dyads or groups as compared to individuals (see Roseth et al., 2008). Fawcett and Garton (2005), for example, showed that 7-year-old dyads performed better on sorting tasks than did individuals. Specifically, children who were paired with a peer of relatively higher ability profited the most from the cooperation. Similar results have been found by others, providing substantial evidence for the importance of dyad composition based on ability level (e.g., Garton & Pratt, 2001). Fawcett and Garton (2005) also provided evidence for Piagetian theory, by showing that dyads who were instructed to talk during a task performed better than individuals and dyads who interacted only minimally, indicating that active interaction was related to cooperative outcomes.

Research has also provided evidence for the importance of dyad composition. For example, Underwood, McCaffrey, and Underwood (1990) compared gender-based homogeneous and heterogeneous dyads' performance in a computerized missing letters task. Children were asked to fill in missing letters to complete a text on the computer screen. They first completed the task individually, then in a dyad, and then again individually (each time for 10 minutes). Homogeneous dyads performed significantly better than individuals, whereas heterogeneous dyads did not differ from individuals. This result shows that, indeed, dyads perform better than individuals, but also that dyad composition matters. Relating this finding to Piagetian theory, it appears that cognitive conflict in and of itself may not (always) be enough to enhance cognitive performance, since gender effects should not have an influence on whether or not there is cognitive conflict (Piaget, 1959).

Social factors, such as friendship and likeability (Johnson & Johnson, 2003; Slavin & Cooper, 1999), and popularity (Oortwijn, Boekaerts, Vedder, & Fortuin, 2008; Puckett, Aikins, & Cillessen, 2008) are also associated with cooperation. For example, it has been shown that cooperative learning programs increase the number of cross-ethnic friendships. Furthermore, friends outperform non-friends on difficult tasks, but not on simple ones (Azmitia & Montgomery, 1993). Friendship may also be the result of increased liking among cooperating individuals (Slavin & Cooper, 1999). This increased liking may result from processes related to cooperation, such as peer encouragement and active participation (Johnson & Johnson, 1985). Cooperative learning can also lead to increased popularity (Oortwijn et al., 2008) and popular children tend to be more cooperative than unpopular children (de Bruyn & van den Boom, 2005; Puckett et al., 2008).

Notwithstanding the potential positive effects of cooperating, research on collaborative memory has shown that due to collaboration, individual memory recall afterwards may be reduced. This phenomenon is known as collaborative inhibition (Rajaram & Pereira-Pasarin, 2010). Potential explanations for this effect are social contagion errors (e.g., an error is believed to be true by the group members), blocking (e.g., an individual blocks and does not share his/her ideas), and retrieval disruption (e.g., problems with retrieving information as a result of other's retrieval strategies). As a result, an individual's learning may be inhibited and individual performance after collaboration may be less optimal. Two potential causes for this inhibition effect are group size (i.e., more inhibition with increased group size; Thorley & Dewhurst, 2007) and the type of memory task (i.e., more inhibition with retrieval tasks compared to cued recall and recognition tasks; Clark, Hori, Putnam, & Martin, 2000; Finlay, Hitch, & Meudell, 2000;). Expertise, on the other hand, can lead to collaborative facilitation (Meade, Nokes, & Morrow, 2009), as can re-exposure and relearning through retrieval (Rajaram & Pereire-Pasarin, 2010). Thus, whether or not collaboration leads to positive outcomes is the result of multiple factors. Next, we propose one such potential factor, one that has not yet been related to cooperative learning, namely the ability to synchronize with others.

Interpersonal Synchrony

A factor that may provide more insight into interaction patterns of cooperative learning, and potentially its working mechanism, is interpersonal synchrony. Interpersonal synchrony can be observed when two (or more) people are doing the same thing at (about) the same time (Bernieri & Rosenthal, 1991; Louwerse, Dale, Bard, & Jeuniaux, 2012). According to Bernieri and Rosenthal (1991) "… normally we invoke our entire body when communicating with others …" (p. 406). Some have even postulated that being able to synchronize behavior with others may be an innate ability in humans (Condon & Sander, 1974; Strogatz, 2003).

Children are already aware of auditory and visual stimuli being synchronous or not at four months of age. When presented with two films and a soundtrack, children at this age already know (i.e., look at) which film is synchronous with the soundtrack that is played (Spelke, 1976, 1979). Recently, it has been shown that, at the end of the first year of life, children prefer synchronously moving social agents (i.e., talking teddy bears) to nonsocial entities (i.e., colored boxes producing sounds; Tunçgenç, Cohen, & Fawcett, 2015). Children chose synchronously rocking teddy bears significantly more often than asynchronously rocking teddy bears, while no difference in choice was found for the nonsocial entities rocking either in or out of sync. From a developmental perspective, the ability to synchronize appears important, because lack of proper attunement (i.e., synchronization) between parent and child negatively affects behavior and affective states (Stern, 1985). Relating this to cooperative learning, being unable to synchronize with others may lead to less optimal outcomes of cooperation, since levels of synchrony and cooperation have been shown to be positively related (Reddish, Fischer, & Bulbulia, 2013; Wiltermuth & Heath, 2009).

Interaction patterns, a factor that is important for cooperative learning (Fawcett & Garton, 2005), also appears important for interpersonal synchrony. For example, during mobile phone conversations, people may synchronize their gait phase angles, but only when actual interaction takes place (Murray-Smith, Ramsey, Garrod, Jackson, & Musizza, 2007). Furthermore, the content of the interaction influences how strongly coupled the gait phase angles are, with free talk leading to the strongest coupling. The interaction does not necessarily have to be verbal to lead to interpersonal synchrony, as it can also be visual. Richardson, Marsh, Isenhower, Goodman, and Schmidt (2007) showed that participants synchronized the tempo of their rocking chairs when they had visual information of the other person without verbal interaction taking place.

Interpersonal synchrony is related to cognition, since higher levels of interpersonal synchrony have been shown to be related to better cognitive performance, such as increased memory (Macrae, Duffy, Miles, & Lawrence, 2008). When more interpersonal synchrony was observed, participants remembered more words they heard during a movement task (i.e., stepping in or out of sync with the experimenter), even though they were instructed to ignore these so-called distracter words. Participants who had been in sync during the experiment also had better memory of the facial features of their interaction partner.

The social context can also be related to the level of interpersonal synchrony observed, with a negative social context being related to lower levels of interpersonal synchrony. For example, Miles, Griffiths, Richardson, and Macrae (2010) showed that when a confederate arrived late for an experiment, there was significantly less interpersonal synchrony between the participants and the confederate than when the confederate arrived on time. Somewhat related is the finding that higher likeability and higher levels of interpersonal synchrony are related (Hove & Risen, 2009). Furthermore, Bernieri (1988) showed that dyads that were rated as being more synchronized were also the dyads whose self-reported rapport was more strongly related.

Power differences can also affect interaction patterns. Dunbar and

Mejia (2012) studied interpersonal synchrony in the interactions between equal- and unequal-power couples. The results showed that interactions of unequal-power couples were predominantly asynchronous, whereas those of equal-power couples were predominantly synchronous. Therefore, difference in power, or related constructs such as dominance and popularity (Cillessen & Rose, 2005), may affect the dynamics of interacting dyads.

Related to these previous findings are those from synchronization research on client-therapist interactions. Ramseyer and Tschacher (2016) showed that interpersonal synchronization of hand-movements occurs in therapeutic client-therapist interactions and that the level of synchrony is related to the quality of the interaction. When there was more interpersonal synchrony, the quality of the interaction was rated more positively. In an earlier study similar results were found with the use of Motion Energy Analysis (MEA), an objective method for quantifying interpersonal synchrony (Ramseyer & Tschacher, 2011). Ramseyer and Tschacher (2011) showed that higher levels of interpersonal synchrony were related to both higher ratings of relationship quality as well as higher self-efficacy. However, this was only the case for the patients, since therapists' ratings of relationship quality did not correlate with the measure of interpersonal synchrony. Thus, interpersonal synchrony is related to social factors in a client-therapist interaction, but how this manifests itself may differ between interacting individuals, potentially due to power differences between them (i.e., difference in status). Furthermore, if one would treat therapy outcome as a kind of performance measure, it may be argued that in this type of interaction interpersonal synchrony is related to (task) performance.

In addition to the synchronization of body movements while cooperating, other physiological measures have also been shown to synchronize. This type of synchronization has also been called physiological compliance (e.g., Henning, Boucsein, & Gil, 2001), which also appears to be related to performance and social factors. For example, Henning et al. (2001) found that stronger physiological compliance of heart rate variability and electrodermal activity was related to better performance on a joint tracking task. In addition, Stevens and Galloway (2016) showed that the level of synchronization of alpha rhythms (obtained from EEG signals) changes as task demands change. Studying a six-man submarine piloting and navigation team while they performed a training simulation, they showed that while performing the simulation the alpha rhythms were desynchronized, while during the debriefing they were synchronized. Stevens and Galloway (2016) suggested that this was due to a reversed attentional state of the team: While performing the simulation, the members were all attending to how the events and activities unfolded, while during debriefing the members were all directed at the instructor or to one of the team members. Thus, characteristics of the task may influence how interpersonal synchrony unfolds.

Since cooperative learning and interpersonal synchrony are both related to cognitive performance and social factors, we set out to examine whether they are interrelated. This idea is based on dynamical or complex systems theory, which states that different time scales, that is, both micro- and macro-levels of performance, need to be considered when describing cooperative learning. Doing this will increase explanatory power (Thelen & Smith, 1994). The next goal of the present study was to examine the potential role of postural sway.

Postural Sway

Interpersonal synchronization has been widely studied by examining postural sway, that is, the instability of the upright stance in humans. Even when standing still, humans show postural displacements (sway) due to the body's constant need to balance. This is a consequence of our evolutionary shift from a quadruple to a bipedal stance, which requires humans to balance in order to stay upright (Skoyles, 2006). Postural sway patterns are informative for studying Parkinson's disease, indicating that there is information in the postural sway patterns which could be informative of other behaviors as well, independent of whether these are healthy or not (Schmit et al., 2006).

During suprapostural tasks (tasks that require postural control to be completed) such as verbal interactions (Shockley, Baker, Richardson, & Fowler, 2007; Shockley, Santana, & Fowler, 2003) or memory tasks (Chen, Tsai, Stoffregen, Chang, & Wade, 2011), postural sway patterns change compared to quiet stance. According to Shockley et al. (2003), these changes occur because the tasks require postural adjustment for successful performance.

Studies also examined changes in postural sway patterns while performing a task together. For example, Shockley et al. (2003) found more shared postural activity in pairs of participants when they were having a conversation with each other than when both were conversing with a confederate who was not in the room. Thus, postural coordination patterns appear to be affected by the presence or absence of a conversational partner, with more shared postural activity observed when the partner is present. Stoffregen, Giveans, Villard, Yank, and Shockley (2009), and Stoffregen, Giveans, Villard, and Shockley (2013) found similar results. More postural coordination occurred when participants were interacting, indicating that a defining factor in these studies was the presence of the interaction partner. Stoffregen et al. (2013) also found that postural coordination increased when both participants looked at the same target. When target sizes matched, participants showed more postural coordination than when there was a mismatch. Thus, looking at the same target or having similar knowledge appears to affect postural coordination as well.

Further support for the effect of suprapostural tasks on postural sway patterns comes from Shockley, Baker, Richardson, and Fowler (2007). They examined the effect of articulation on postural coordination and found that articulation indeed had an effect on postural sway coordination, but this coordination was only visible within participant pairs that performed the task together. There was no postural sway coordination in surrogate participant pairs. Again, this shows that unintentional interpersonal coordination can take place only when there is the possibility to interact.

Present Study

The main goal of this study was to better understand the internal synchronization processes of dyad coordination that lead to increased performance. This could provide insight into the underlying process that takes place during a cooperative learning task, since Thelen and Smith (1994) stated that "the power of explanations is in the dynamics of the processes" (p. 39). Based on previous research, which has shown that humans spontaneously synchronize movements (Condon & Sander, 1974; Strogatz, 2003), we expected to find higher levels of interpersonal synchrony when cooperating. More specifically, we expected interpersonal synchrony to be related to cognitive performance (Macrae et al., 2008), the level of likeability between the cooperating individuals (Hove & Risen, 2009), and the social context (Miles et al., 2010), as defined by the levels of social acceptance and popularity of the members of a dyad.

We hypothesized that dyads would perform better on a cognitive task (tangram puzzles) than individuals, as suggested by previous research (Fawcett & Garton, 2005; Underwood et al., 1990). Furthermore, we expected social factors, namely social acceptance, likeability, and popularity, to impact cognitive performance. Specifically, more accepted and more popular dyads were expected to perform better. This hypothesis was derived from de Bruyn and van den Boom (2005), who showed that popularity and cooperation were positively correlated. Support for our hypotheses would provide additional support for the positive effects of cooperation and its association with social factors and cognition.

METHOD

Participants and Procedure

In this study, eight schools participated with 18 classrooms, including 392 children between the ages of 8 and 13. These children formed 196 dyads. Children were randomly assigned to dyads, with the only prerequisites that the dyad should be same sex and from the same classroom. In a few cases, there were technical failures with data recording. In some classrooms with an uneven number of children, one child participated in two dyads or in a dyad with an opposite sex peer (so that all children could participate in the task). As a result, 13 dyads were removed from the analyses yielding a final analysis sample of 183 dyads (M_{age} = 10.7 years, SD = .88, range: 8-13; 95 boys and 88 girls).

Participants were recruited via letters that were sent to a large number of Dutch primary schools. Two weeks later, schools were contacted to inquire whether they wanted to participate. Schools that wanted to participate were sent additional information via email, including a letter for parents. In this letter, parents were notified of the participation of their child's school, given information about the study, and asked whether they allowed their child to participate or not. Teachers informed the researchers of the total number of participants and provided a list with names of the children whose parents gave consent for participation.

Measures

Sociometric Questionnaire

The sociometric questionnaire began with demographic questions (sex, birth date, parents' nationality, language(s) spoken at home), followed by standard sociometric questions for likeability ("*Who do you like most/least?*") and popularity ("*Who is most/least popular?*"). This questionnaire also included a likeability rating ("*How much do you like this classmate?*"), in which children were asked to rate each classmate on a 6-point Likert scale, ranging from 1: '*dislike a lot*' to 6: '*like a lot*'. To make the questionnaire anonymous, children received a roster with the names of their classmates preceded by a code number. Children were asked to use the code numbers when nominating peers, not names.

In the classroom, each child was handed a questionnaire and a list with names and code numbers. Next, the researcher explained how to fill in the questionnaire; children were instructed not to use names, that they could nominate an unlimited number of classmates, and that they could not nominate themselves. When finished, the children could either color a drawing on the back of the questionnaire or work on something else. After completing the questionnaire, the researcher collected the questionnaire and the list with names.

Sociometric Status

SocStat (Thissen-Pennings & Bendermacher, 2002) was used to analyze the data obtained with the sociometric questionnaire. First, it counts how many nominations an individual received for each item. Next, it transforms this number into a standard *z* score, specific to the class the individual belongs to. In the present study, we used composite scores for popularity, derived from the questions "*Who are most/least popular?*" and peer acceptance, derived from the questions "*Who do you like most/least?*". This means that *z* scores were based on the number of positive nominations received minus the number of negative nominations received (Mayeux, Houser, & Dyches, 2011).

To determine the popularity and acceptance of the dyad, two calculations were performed. First, average dyadic popularity was computed by taking the average of both individuals' composite popularity scores. Second, dyadic difference scores for popularity were calculated by taking the absolute difference between both the popularity scores of both dyad members. For peer acceptance, dyadic average and dyadic difference scores were computed in the same way. In addition, dyadic likeability scores were computed by taking the average and difference of the individual likeability ratings of the dyad members.

Nintendo Wii Balance Boards

Two Nintendo Wii Balance Boards (WBBs; Nintendo, Kyoto, Japan) were used to record the postural sway of each dyad member simultaneously. Previous research has shown that the WBB is an inexpensive and more easily moveable alternative to the more expensive and less portable force platforms used in clinical settings, while still being a reliable device for measuring postural sway (Clark et al., 2010; Clark, McGough, & Paterson, 2011). For the data collection a custom-made Microsoft Windows-based program for dual WBB recording (Voogt, TSG-FSW, Radboud University, The Netherlands) was used with a sampling rate of 100 Hz. The recorded measures included the medial-lateral (X-axis) and anterior-posterior (Y-axis) direction of sway. In line with previous studies (Koslucher et al., 2012; Stoffregen, Chen, Varlet, Alcantara, & Bardy, 2013), we did not filter the data, since we believe that noise is also part of a system's behavior and filtering could remove potentially interesting data.

Tangram Task

Figure 1 presents an example of a tangram puzzle. A tangram puzzle consists of seven pieces that can form all sorts of figures. We used three sets of puzzles containing 18 different puzzles each (i.e., 54 different puzzles in total). The figures were printed in black on A4 paper and the children were asked to lay the pieces on top of the figure in order to recreate the figure.

Fig. 1. Example of a tangram puzzle.

In the week(s) following the sociometric questionnaire, the dyadic part (i.e., the tangram task) took place. Children were randomly assigned to same-sex dyads. Upon entering the room, which was assigned to the experimenter by the school (e.g., an unused office), the children were instructed to step onto their Wii Balance Board[1] (see Fig. 2 for a birds-eye view of the experimental setup). Here, the WBBs were placed approximately 70 centimeters apart. First, they were given information about the experiment, including the presentation of an example tangram puzzle and a demonstration on how to complete the puzzles. If there were no questions and the children were ready, the experiment began.

In the first part of the experiment, the children had 10 minutes to recreate as many tangram puzzles as possible, with the number of puzzles correct being used as *individual task 1* score. Each child was presented with his or her own set of puzzle pieces and a set of tangram puzzles. Each set contained different figures, so peaking was of no use. Although they were asked to perform as best as they could, it was not meant to be a competition. The children were asked to notify the researcher when they had finished a puzzle. If they did this correctly, they were allowed to continue with the next puzzle, otherwise they had to keep trying. Only when a child had made many unsuccessful attempts, he or she was allowed to skip that puzzle. After 10 minutes, the children were prompted to stop and step of their WBB.

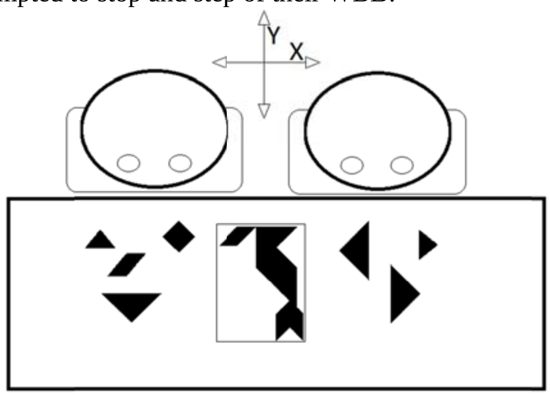

Fig. 2. Birds-eye view of the experimental setup, showing the children standing on their individual Wii Balance Board, facing the table on which the puzzle and puzzle pieces are placed. The arrows indicate the direction of sway.

For the second part, the researcher moved the WBBs closer to each other, approximately 10 centimeters apart, and the children were again asked to step on their WBB. One set of puzzle pieces was removed from the table and the dyad was presented with one new set of tangram puzzles. Again, the goal was to recreate as many puzzles as possible within 10 minutes, but this time the children could cooperate, with the number of puzzles correct being used as the *cooperative task* score. Everything else was similar to the first part. Note that we decided to have the children perform the task while standing next to each other. This way, both children saw the puzzle from the same direction. Furthermore, this set-up allowed studying interpersonal synchrony in the context of standing next to each other.

Finally, the children were asked to perform the task alone once more, exactly as in the first part. Here, the number of puzzles correct was used as *individual task 2* score. After this part, the experiment was finished. As a token of gratitude, the children were given a small present for their participation (e.g., a pen or eraser).

Data Preparation

Interpersonal Synchrony

Concerning interpersonal synchronization, there are two possible directions in which it can occur. The first is in-phase synchrony, that is, movement in the *same direction* (stable 0° relative phase; see Fig. 3A). In the present investigation, this would entail both children swaying in the same direction. To examine this, we performed CRQA (method discussed in the next paragraph) on the time-series in their original format. The second possibility is anti-phase synchrony, that is, synchronized movement in the *opposite direction* (stable 180° relative phase; see Fig. 3B). More specific for the present study, this occurs when both children either move in exactly the opposite direction, that is, either towards each other/the task or away from each other/the task. In-phase synchrony may be observed when children take turns at solving the puzzle, moving like the pendulums in Fig. 3A. However, if the children are both working on the puzzle, anti-phase synchrony may be observed, thus moving like the pendulums in Fig. 3B. As it was unclear what to expect, and both directions of synchrony were possibilities in the present investigation, we decided to examine both. To examine this, we performed CRQA on one original time-series and one *flipped* time-series: all values of the original time-series were multiplied by -1. This way, values that were (perfectly) out of sync became (perfectly) in-sync. However, this is not to say that we only examined perfect in- and anti-phase synchrony. Perfect synchrony is rarely observed in behavior, and as we mentioned in the Method section, we chose a recurrence rate of 5%. Thus, in order to get to this 5% rate, small deviations from perfect synchrony were allowed.

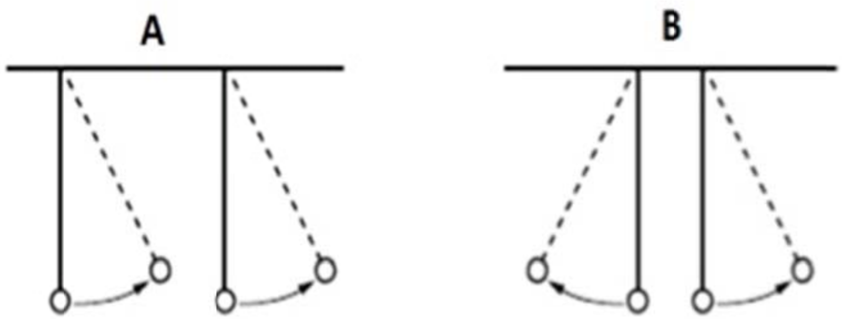

Fig. 3. In-phase (A) and anti-phase (B) synchrony.

Cross Recurrence Quantification Analysis

Data reduction was first performed on the original data. The reason for this was that the available memory of the computer used for the analyses was insufficient. The original sampling rate was 100 Hz, which we down sampled to

5 Hz, resulting in time series of approximately 3,000 data points per dyad. The postural sway data, collected with the WBBs, were analyzed with the use of Cross Recurrence Quantification Analysis (CRQA). This method is especially useful for the study of interpersonal synchrony, as it can detect and quantify occurrences of synchronization over time (Shockley, 2005).

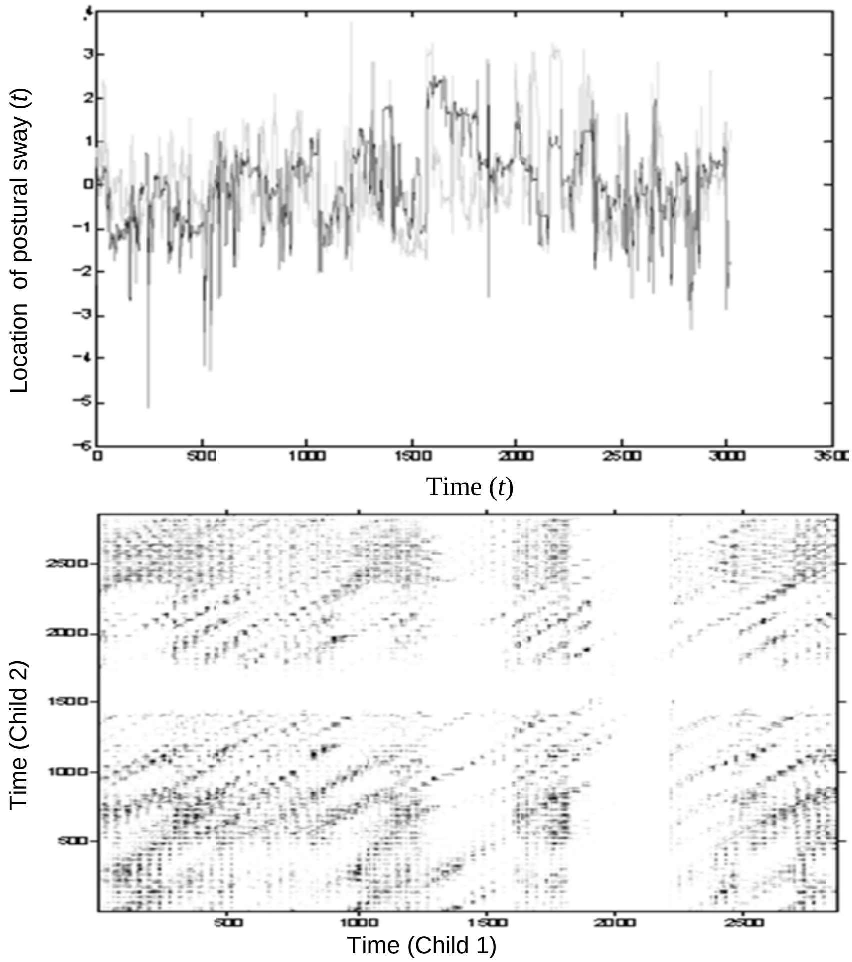

Fig. 4. Time series (upper) and Cross Recurrence Plot (lower) of a real dyad.

To perform CRQA analyses, the shared phase space of the dyadic time series was reconstructed using the method of time-delayed embedding (Takens, 1981). To determine an appropriate delay, the Average Mutual Information (AMI) was calculated over increasing time lags. The time lag where the first local minimum (hence, the point where the time series reveal an optimum amount of unique information) appeared was chosen for the reconstruction (40 data points). Next, the embedding dimension (5) was determined by a first local minimum of False Nearest Neighbors (FNN; cf., Riley et al., 1999). The radius (i.e., the area in the shared phase space where revisiting trajectories are considered recurrent) was allowed to vary within each dyad, so that the recurrence rate within each dyad was exactly 5% (cf. Wijnants, Bosman, Hasselman, Cox, & Van Orden, 2009). These parameters were used to optimize the reconstruction. However, as Riley, Balasubramaniam, and Turvey (1999) stated, for recurrence analyses on postural sway data, the choices for time lag and embedding dimension are not crucial.

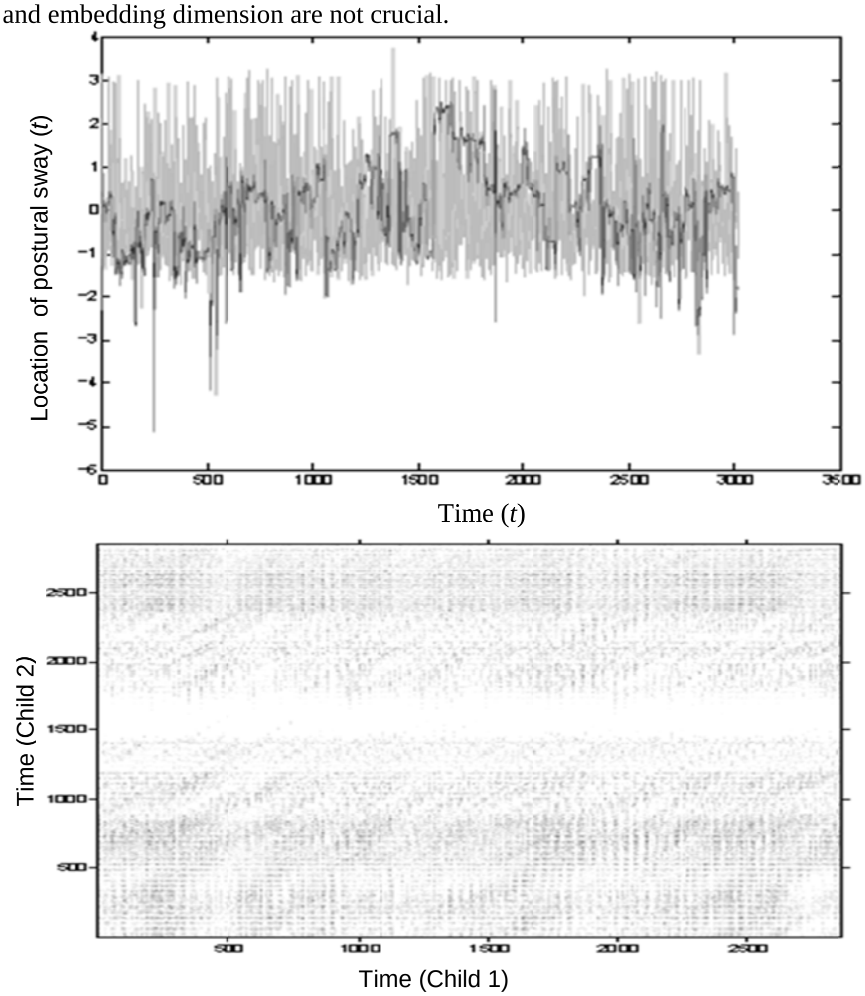

Fig. 5. Time series (upper) and Cross Recurrence Plot (lower) of a shuffled dyad (black is the original time series).

The resulting measures included percent determinism (*%DET*), the number of recurrent points forming a line of at least two recurrent states (i.e., the predictability of the pattern), meanline (*MEAN*), the average diagonal line length of recurrent points (i.e., the average time in sync), entropy (*ENT*), the Shannon entropy as a measure of the complexity of shared activity, and the radius that yielded a recurrence rate of 5% (Shockley et al., 2003). The CRQA analyses were performed in Matlab® (Mathworks Inc., 2012) with the use of the Cross Recurrence Plot (CRP) Toolbox (http://tocsy.pik-potsdam.de; Marwan, Romano, Thiel, & Kurths, 2007).

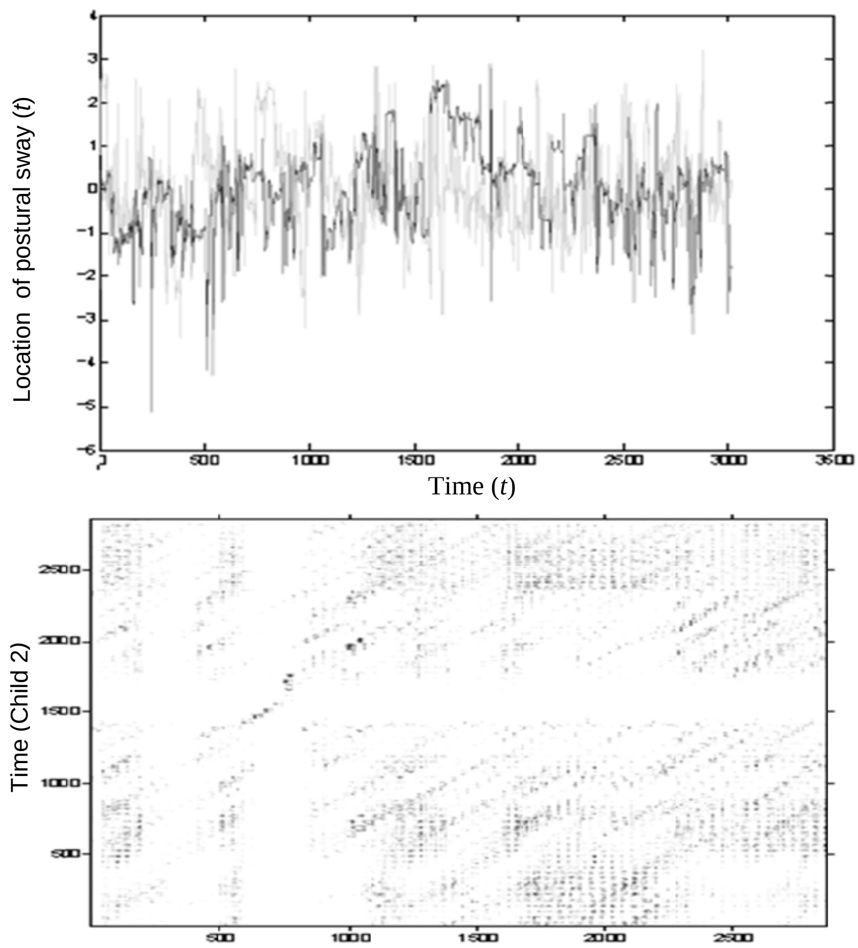

Fig. 6. Time series (upper) and Cross Recurrence Plot (lower) of a virtual dyad (black is the original time series).

Surrogate Analysis

To reassure that the measures obtained from the CRQA analyses are dyad specific, and not obtained by chance, we performed two surrogate analyses to check for this. First, we compared the CRQA results from the real dyads with those from dyads in which the original postural sway time series of one of the members of a dyad was coupled with the randomized time series of the other member of the dyad. Figures 4 and 5 show these time series and the accompanying CRPs. In a CRP, one time series is plotted on the X-axis and one on the Y-axis and when there is synchrony, a dot is placed on that coordinate. An independent samples *t*-test was performed to check for differences between %DET of the real and shuffled dyads. %DET of the real dyads was significantly higher (M = .80, SE = .005), than that of the shuffled dyads (M = .18, SE = .005), $t(362) = 93.15$, $p < .001$, $d = 9.79$, indicating that the time series of the real dyads were considerably more synchronous than time series that have lost their temporal structure.

As a second check, we compared the results of the real dyads (i.e., real interactions) with those of virtual dyads (i.e., pseudo interactions). This method has been suggested by, for example, Bernieri and Rosenthal (1991). Figure 6 shows the CRP for these time series. Here, we paired members of two different dyads, resulting in dyads of which the members did not actually cooperate. To make these dyads as comparable as possible, we paired one member who was positioned on the left WBB with a member who was positioned on the right WBB and both members had to be from the same class. Furthermore, for the CRQA analyses on the virtual dyads we used the same radius that yielded a recurrence rate of 5% in the real dyads. Next, we performed an independent samples *t* test to check whether %DET differed between real and virtual dyads. Here, %DET was also significantly higher for the real dyads (M = .80, SE = .005) than for the virtual dyads (M = .68, SE = .01), $t(265.66) = 11.21$, $p < .001$, $d = 1.38$. This test indicates that the results are dyad specific, not merely the result of the task constraints.

RESULTS

First, we examined changes in cognitive performance and social factors between the individual tasks and cooperative task. We also examined how these factors were correlated. Second, we examined how cognitive performance was related to interpersonal synchrony. And third, we examined how social factors were related to interpersonal synchrony.

Cognitive Performance and Social Factors

Table 1 presents the descriptive statistics of individual social acceptance, popularity, and cooperative task scores (i.e., tangram task). Furthermore, the dyadic cooperative task score is presented, as well as the dyadic means and differences for social acceptance, popularity, and likeability. Table 1 only contains those individuals who were in a dyad that was eligible for inclusion in the analyses, thus the number of individuals is lower than the total number that participated in this study.

Table 1. Descriptive Statistics of Individual and Dyadic Research Variables.

	N	*M*	*SD*	Minimum	Maximum
Individual					
Individual task 1	366	5.73	2.29	0	14
Individual task 2	364	7.47	3.06	0	16
Social acceptance	366	-.03	1.00	-3.28	2.15
Popularity	366	.02	1.02	-3.08	2.81
Dyadic					
Cooperative task	183	9.17	2.56	5	15
Popularity					
Difference	183	1.16	.92	0	5.19
Average	183	.02	.71	-2.20	1.76
Social acceptance					
Difference	183	1.01	.86	.00	4.20
Average	183	-.03	.75	-2.55	1.78
Dyadic likeability					
Difference	179	.88	1.01	0	4
Average	179	4.77	1.02	1	6

Table 2. Correlations of Individual and Cooperative Task Scores with Social Factors.

	Individual Task 1	*Cooperative Task*	*Individual Task 2*
Individual			
Social acceptance	**.11***	-	.04
Popularity	< .01	-	< .01
Dyadic			
Popularity			
Difference	-	-.05	-
Average	-	-.03	-
Social acceptance			
Difference	-	-.03	-
Average	-	.06	-
Dyadic likeability			
Difference	-	< .001	-
Average	-	-.02	-

Note. * $p < .05$

First, independent samples *t* tests were performed to examine differences between the cooperative and individual tasks. The results showed that cooperative scores were significantly higher than scores on individual task 1, $t(331.14) = -15.38$, $p < .001$, $d = -1.69$, and individual task 2, $t(545) = 6.48$, *p*

< .001, *d* = .56. Scores on individual task 2 were significantly higher than those on individual task 1, *t*(672.88) = -8.68, *p* < .001, *d* = -.67. Thus, the highest scores were obtained when cooperating and there was a significant increase in the number of puzzles solved between the individual tasks, confirming the hypothesis that dyads perform better than individuals and that individuals performed better over time.

Pearson correlations were calculated to examine the associations between test scores and acceptance, popularity, and likeability. Table 2 shows the results for individuals and dyads. There were no significant associations between cognitive scores and any of the social measures, except for a small positive correlation between individual task 1 scores and individual social acceptance.

Cognitive Performance, Social Factors, and Synchronization

First, the associations between the dyadic measures of cognitive performance (i.e., cooperative task score) and social factors (i.e., acceptance, popularity, and likeability) and the measures of interpersonal synchrony of postural sway, both in- and anti-phase, were examined. As Table 3 shows, there were significant negative correlations between the cooperative task scores in *both* the in- and anti-phase measures of interpersonal synchrony in the side-to-side sway (X-axis). Thus, less synchronized dyads performed better than more synchronized dyads, being it either in the same or opposite direction.

Concerning the front-to-back sway (Y-axis), there were significant positive correlations between the average popularity of the dyads and both the in-phase and anti-phase synchrony measures (see Table 4). Thus, dyads who were on average more popular showed significantly higher levels of interpersonal synchrony in both the in-phase and anti-phase front-to-back sway patterns. In other words, on average more popular dyads synchronized more in the same and in the opposite direction. Social acceptance and likeability scores were not significantly correlated with any of the measures of postural sway. In sum, the results showed that lower levels of in- and anti-phase interpersonal synchrony were observed in better performing dyads and higher levels of in- and anti-phase interpersonal synchrony were observed in dyads that were on average more popular.

DISCUSSION

The goal of this study was to examine interpersonal synchrony of postural sway during cooperation and its association with task performance and social factors (acceptance, popularity, and likeability). The results showed a negative association between cognitive task performance and interpersonal synchrony on the X-axis, as well as a positive association between the average popularity of a dyad and interpersonal synchrony on the Y-axis. In both cases, the results were found in both the in- and anti-phase measures of interpersonal synchrony. No significant associations were found between interpersonal synchrony and social acceptance or dyadic likeability.

Table 3. Correlations Between Dyadic Cognitive Performance and Measures of Interpersonal Synchrony of Postural Sway.

	In-phase (N = 182)						*Anti-phase (N = 181)*					
	X-axis			*Y-axis*			*X-axis*			*Y-axis*		
	%DET	*MEAN*	*ENT*	*%DET*	*MEAN*	*ENT*	*%DET*	*MEAN*	*ENT*	*%DET*	*MEAN*	*ENT*
Performance	**-.22****	**-.19***	**-.22****	**-.16****	-.09	-.13	**-.24****	**-.20****	**-.24****	**-.16***	-.11	-.13

Note. * p < .05, ** p < .01

Table 4. Correlations Between Dyadic Social Factors and Measures of Interpersonal Synchrony of Postural Sway.

	In-phase (N = 182)						*Anti-phase (N = 181)*					
	X-axis			*Y-axis*			*X-axis*			*Y-axis*		
	%DET	*MEAN*	*ENT*	*%DET*	*MEAN*	*ENT*	*%DET*	*MEAN*	*ENT*	*%DET*	*MEAN*	*ENT*
Popularity												
Difference	-.04	.01	-.03	.06	.11	.09	-.01	.07	.03	.03	.04	.04
Average	.03	.04	.06	.12	**.16***	**.15***	.06	.08	.09	.12	**.16***	**.15***
Social acceptance												
Difference	.02	< .01	.01	.01	.02	.01	.01	.03	.02	.01	.01	.01
Average	.04	< -.01	.02	.05	.03	.02	.03	-.02	.01	.04	-.01	< .01
Dyadic likeability												
Difference	-.08	-.05	-.09	-.09	-.06	-.07	-.08	-.03	-.06	-.11	-.09	-.09
Average	.07	< -.01	.05	< -.01	.03	.02	.07	-.03	.01	.03	.07	.06

Note. * p < .05

The results for task performance correspond with previous research, which also showed that working together could lead to better task performance than working individually (e.g., Blaye, Light, Joiner, & Sheldon, 1991; Hooper, 1992; Hooper, Temiyakarn, & Williams, 1993; Johnson & Johnson, 1999; Johnson, Johnson, & Skon, 1979; Johnson, Maruyama, Johnson, Nelson, & Skon, 1981; Roseth, Johnson, & Johnson, 2008). When working together, dyads can discuss, elaborate, and challenge ideas, which is not possible when working alone (Johnson & Johnson, 1999). Social factors, however, were unrelated to task performance when either working alone or cooperating. A potential explanation is that in cooperative learning students might build more positive peer relationships as a result of interacting during the task (Roseth et al., 2008). Thus, performance may be less related to predetermined social factors, such as popularity, acceptance, and likeability, but more so to social interactions taking place while actually cooperating. An additional explanation is that social relationships are quite robust and unaffected by task performance (Hinde, 1976) or that individuals do not judge each other on reputation, such as popularity or social acceptance, but on their merits (Slavin & Cooper, 1999).

We showed that more interpersonal synchrony does not necessarily mean better task performance. This may seem surprising considering previous findings (e.g., Macrae et al., 2008; Miles et al., 2010). However, when standing next to each other, synchronizing may be inefficient. Abney, Paxton, Dale, and Kello (2015) also showed that more interpersonal synchrony does not always mean better task performance. In certain contexts synchronizing may not be functional. They showed that, using a dyadic problem-solving task (i.e., participants had to build a tower as high as possible using marshmallows and raw spaghetti), weakly coupled (i.e., less synchronized) dyads performed best. This finding is in line with the results from the present study that less synchronized (i.e., weakly coupled) dyads performed better than more synchronized (i.e., strongly coupled) dyads. Thus, in certain contexts it may be more important to coordinate instead of synchronize with one another. Or, as Guastello (2016) stated, there may be "… a balance that needs to be identified for any given situation" (p. 54). In the present study, the children worked simultaneously on the task, such that they had to coordinate their movements in order to avoid collisions and at the same time maintain working on the task. Thus, their movement patterns needed to be complementary (Richardson et al., 2015). The finding that less synchrony was associated with better task performance could be an indicator of more complementary coordinated movements, whereas synchronous movements would indicate more individual behavior (i.e., when one is working, the other gets out of the way) or less flexible behavior (i.e., both are simultaneously directed or not directed towards the task).

We believe that it may sometimes be more important to coordinate than to synchronize, which is supported by Guastello and Guastello (1998). They stated that coordination may be learned implicitly next to learning a task explicitly. When relating this to the results of the present study, we can hypothesize that the children explicitly learned the puzzle task while implicitly learning to coordinate their postural sway. The finding that better task performance correlates with less synchronized postural sway supports this hypothesis, since those dyads that performed best (i.e., better explicit learning) synchronized less, that is, coordinated better (i.e., better implicit learning).

At first glance, it may seem odd that less interpersonal synchrony was observed in better performing dyads. Note, however, that according to Piaget's theory (1959) conflict or competitive interactions, such as discussing, explaining, or challenging one another's ideas, may lead to cognitive growth. If so, this may result in less interpersonal synchrony when working together. Support for this is provided by Paxton and Dale (2013), who showed that individuals who were engaging in argumentative interactions showed reduced levels of synchronized bodily movements.

With respect to popularity, we showed that more popular dyads showed on average more interpersonal synchrony in the front-to-back direction for both the in- and anti-phase synchrony levels. Perhaps popular children are more prosocially skilled than unpopular children (Newcomb, Bukowski, & Pattee, 1993). In addition, previous research has shown that prosociality is related to measures of dyadic synchrony, for example between mother and child (Lindsey, Colwell, Frabutt, Campbell Chambers, & MacKinnon-Lewis, 2008). Thus, the higher observed interpersonal synchrony in on average more popular dyads may be the result of the higher levels of prosocial behavior of the dyad.

Additional research should further examine the linkages between task performance, social factors and interpersonal synchrony in relation to cooperative learning. Although we provided new insights into the working mechanism of interpersonal synchrony in cooperative learning situations, many questions still remain. For example, are similar results observed when participants are facing each other instead of standing next to one another? In previous research, participants stood behind or in front of one another, instead of next to each other (Shockley et al., 2003). Synchronizing with the person in front of you may be easier than with someone standing next to you, as there is more visual information available about what the other person is doing. However, in the present study, children may not have been able to synchronize their movements, as the task could cause them to be in each other's way. Thus, the task may have provided a physical boundary which may have made it more difficult to synchronize with one another. Another question that future studies may address is whether speech is related to postural sway, and if so, if (and how) this changes the results of the present study.

Gaining more insight into these mechanisms and their correlates can further develop theory about cooperative learning, which in turn may lead to new insights in how to structure cooperative learning tasks, for example in schools, in order to increase the potential for students to reach higher levels of academic achievement. In a follow-up study, we will examine a group of children with developmental disabilities and we will relate these findings to the ones of the present study. This way, we hope to provide a more complete picture of how interpersonal synchrony is related to task performance and if, and how, this differs between different groups of children.

ENDNOTES

[1]Note that the data collected with the Wii Balance Boards from the individual tasks will be discussed in another paper. Here, we only focus on the cooperative task.

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