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The Influence of Shared Intentions With Others in Physical and Cognitive Tasks That Require Collaborative Solving in Elementary School

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Developing the competence to share intentions with others is an important role of elementary schools for the children's future well-being. We analyzed and clarified the relationship between physical and cognitive tasks that require collaborative solving to cultivate the skill of sharing intentions with others through human movement. As a physical task, we designed a tag game in which two defenders prevented three attackers from passing through to reach the goal line. We focused on the defenders' movement in the game and analyzed the efficiency of each defender's movement as an individual behavior and the interpersonal distance between these two defenders as a pair behavior. As a cognitive task, we examined pair activities when understanding concepts in math classes. We observed talking and listening behaviors during the pair activities and analyzed the responsive behavior as an individual behavior, which comprised responsive utterances and active listening from the listener's gaze direction. Role change during pair activities in math lessons was analyzed as a pair behavior. We then analyzed the relationship between behaviors in both tasks. The hypotheses were as follows: (1) task constraints lead to an interaction between individual and pair behaviors in both tasks and (2) individual and pair behaviors in the two tasks have similar characteristics. The results from both tasks support the first hypothesis that the efficiencies of individual movement and interpersonal distance in the tag game and the frequencies of responsive behavior and role changes in the pair activities in math classes are positively correlated. The results also support the second hypothesis that the individual and pair behaviors in the two tasks are significantly correlated. These results suggest that the competence to share intention with others is fundamental regardless of the task nature: physical or cognitive. The findings suggest that the task constraints of joint action in physical education lead to an understanding of the task goals and to exploring the solution for winning. These experiences might be generalized to all cognitive tasks for cultivating the competence to share intentions with others.

Keywords: tag game, pair activity, efficiency of individual movement, interpersonal distance, responsive behavior, role change

INTRODUCTION

Cultivating the Competence to Share Intentions With Others in School Education

The Organization for Economic Co-operation and Development [Organisation for Economic Co-operation and Development [OECD], 2018] presents the OECD learning compass as a framework to achieve a desirable future for education. As its central concept, "agency" refers to the sense of responsibility to influence people, object, and the environment through social participation. To become an agent, one must collaborate with others to find and solve problems. Because people live in a dynamic and uncertain environment where they cannot understand everything, competence in inferring (Cohen, 1995) and in sharing (Tomasello, 1999, 2009) intentions are essential to finding and solving problems with others. Aside from the acquisition of scientific knowledge, the future of education calls for competence in inferring and sharing others' intentions.

The competence to infer and share the intentions of others has been examined in the learning sciences as collaborative problem-solving skills (Miyake, 1986; Shirouzu et al., 2015) and general classroom social norms (Cobb et al., 2001). Collaborative problem-solving skills improve in quality as they build on domain-specific learning experiences. General classroom social norms develop through interaction with "sociomathematical norms" (Yackel and Cobb, 1996). Both have commonly been examined in the process of solving domain-specific cognitive tasks. As such, current school education mainly depends on developing domain-general skills while exploring domain-specific or interdisciplinary cognitive tasks. Schools mainly adopt a cognitive approach. In fact, Battelle for Kids (2019) lists English, reading or language arts, world languages, arts, mathematics, economics, science, geography, history, government, and civics as subjects designed to foster 21st-century skills. Even in the arts, collaboration is assumed to develop through verbal communication (Dean et al., 2010).

Sharing Intentions With Others as the Foundation of the Sensorimotor System

The development of the sensorimotor system is fundamental to achieving competence in inferring or sharing the intentions of others. Mascolo and Fischer (2015) described the developmental tiers of empathy with others as beginning with reflexes shortly after birth, recognizing the relationship between one's own experience and that of others through sensorimotor actions, and developing representational concepts. In a more detailed overview of human development, we found that infants synchronize their rhythms with others shortly after birth (Kato et al., 1983; Provasi et al., 2014). Specifically, at the age of 6 months, infants show dyadic engagement in sharing behaviors and emotions. Individuals generally interact with others through emotional expression and turn-taking behaviors. At the age of 9–12 months, infants start showing triadic engagement in sharing goals and perceptions. At this stage, an infant may interact with a goal-directed agent toward a shared goal, and both may interact perceptually to monitor the goal-directed behavior and perceptions of their partner (Tomasello, 1999; Tomasello et al., 2005). In this developmental stage, infants understand others as intentional agents in goal-directed behavior by following the actions and attention of such agents. Moreover, cooperative engagement to select plans and share intentions becomes possible through the following three types of social cognition (Tomasello, 1999). The first is "joint attentional scenes," through which infants understand others' intentions and share context with others. The second is "communicated intentions," through which infants understand others' intentions toward their own state of attention. The third is "role-reversal," through which infants understand the roles of others and the self and can exchange roles when necessary. Even among young children, intentions can be shared because they can learn from watching and listening to others, as demonstrated by statistics, informal experiments, and Bayesian inference (Gopnik, 2012; Gopnik et al., 2017).

In other words, human development begins with empathetic identification through the physical synchronization and expression of emotions. The understanding and sharing of intentions with others emerge from physical information such as gaze direction and action based on the self–other distinction. This physical information then develops into domain-specific cognitive and physical tasks. In elementary school education, where the sensory-motor system is not sufficiently developed, it is important to have experiences of inferring and sharing the intentions of others through human movement interactions.

A Joint Action Requires the Sharing of a Goal and Intention

Recently, many studies have examined "joint action," which requires the sharing of intentions and goals with others. Knoblich et al. (2011) classified joint actions into "planned" and "emergent" coordination. Planned coordination involves intentional efforts to achieve a common goal, and consists of shared task representations and joint perceptions. Joint action is driven not only by action plans that specify individual contributions but also by action plans that specify joint action outcomes at the group level (Kourtis et al., 2019). In particular, complex tasks indicate that complementing rather than synchronizing actions may lead to superior task outcomes (Wallot et al., 2016). Meanwhile, emergent coordination refers to the spontaneous coordinated actions occurring through bottom-up perception–action coupling without a shared plan. This can be considered as the result of entrainment (Néda et al., 2000; Richardson M. J. et al., 2007), affordances (Gibson, 1977), perception–action matching (Calvo-Merino et al., 2005; Cross et al., 2006), or action simulation (Aglioti et al., 2008). Notably, many joint actions include both emergent and planned coordination to facilitate collective behavior (Richardson D. C. et al., 2007; Knoblich et al., 2011). Emergent cooperation within planned cooperation enables maintaining jointness and cooperation. Consequently, the cognitive effort to achieve a common task goal is reduced (Milward and Carpenter, 2018).

Tomasello (1999) suggested that "joint attentional scenes," "understanding [of] communicative intention," and "role reversal" are the bases of social cognition in language acquisition. In a joint attentional scene, the purpose shared is perceived as "what we are doing," rather than merely looking at the same object. While the purpose is shared, planned coordination develops through the understanding of communicative intention, where pairs share what they are doing in order to direct attention to each other. In other words, the constraints of the task, which require sharing the task and coordinating, are essential to the establishment of a joint action, in contrast to performing the task separately.

Required Individual Behavior for Joint Action

One example of a joint action that requires a shared goal and intention is interpersonal sports. Because sports unfold continuously, the emergent movements are created through planned coordination. Kijima et al. (2012) examined the changes in strategies in repeated competitive situations in one-on-one "play-tag" by observing the movements of two players and interpersonal distances. They found that as the game was repeated, participants guessed the intentions of others and chose a not-to-lose strategy, resulting in a deadlock situation. This study demonstrates that an understanding of each other's intentions in competing joint actions is observable through interpersonal distance. In addition, Yokoyama and Yamamoto (2011) found that expert triad coordination requires sharing intentions with two other partners in a three vs. one ball-possession task. Yokoyama et al. (2018) quantified social forces consisting of spatial, avoiding, and cooperative forces, which were critical for successful triad coordination. In other words, in group sports, proficiency appears in individual movements (distance and angle, among others) within triad coordination. The authors suggested that sports skills include not only individual skills such as running and ball handling but also interpersonal skills to cooperate with others. In sports activities, quick decision-making and execution are necessary to respond to others' various movements. Thus, interpersonal coordination that is based on shared intention might help in achieving the team's goal. Successful interpersonal coordination in sports requires each individual to infer what information others perceive from the environment and then share their intentions with each other.

Another example of a joint action that requires the sharing of goals and intentions is a collaborative cognitive task. The listener must pay attention to the content of the conversation and understand the thoughts of the other person while listening. Meanwhile, the speaker must convey his or her thoughts to the listener while simultaneously choosing content that matches the other person's understanding. For example, one way to check whether the listener is interested in the dialog and is trying to understand what the speaker is saying is through nodding or the "back channel" (Yngve, 1970). The back channel is the listener's response to the speaker, but this is not established by the listener's efforts alone. Nodding and back channels are created when the speaker checks if the listener understands the message and encourages the listener to participate in a conversation. Particularly, in Japanese, the speaker's use of final particles such as "ne," "sa," and "yo" creates a context that encourages the listener to engage in dialog. Compared with English, Japanese is said to have more "in-progress" back channels. This is because the Japanese language is culturally characterized by harmony and cooperation, which often encourage engagement in conversation (Clancy et al., 1996; Kita and Ide, 2007). In other words, the conversation between two people is not a normative, static phenomenon but rather, a dynamic, context-dependent structure in which the conversation continuously develops through interactional routines, when viewed from a synergistic approach (Fusaroli et al., 2013). Through dialogic interactions, interlocutors jointly profile relevant content and distribute complementary (and often flexibly interchangeable) roles to meet the needs of the tasks at hand. In a collaborative cognitive task, participants are expected to obtain from others information about the cognitive task according to their roles and develop activities in response to the collected information.

The Possibility of Developing Competence in Sharing Intentions Through Human Movement

Abundant studies exist on the relationship between human movement and sociality based on entrainment or synchrony. Cirelli et al. (2016) clarified the effects of synchronous movement on the development of social relationships by showing that increased helpfulness after synchronous bouncing extends to affiliates of the bouncing partner, but not to people showing no specific affiliation to that person. Atherton et al. (2019) found a decrease in negative attitudes toward the Roma social group after participants walked synchronously with Roman participants. It has also been reported that intentional synchronization, such as dancing, tends to increase sociality compared with unintentional synchronization (Lakens and Stel, 2011; Reddish et al., 2013) and that the effects of synchronization on interpersonal relationships persist for 24 h (Cross et al., 2020). Synchronization and entrainment negate the self–other distinction, which can increase interpersonal empathy (Hove, 2008).

Sebanz et al. (2006) reviewed joint action research and identified future work to examine the common principles between non-verbal forms of joint action and language. Pezzulo et al. (2019) showed that the experience of sensorimotor communication can serve as scaffolding for more complex forms of communication such as mind reading and verbal communication. In interpersonal sports, it is necessary to integrate oneself and others based on entrainment or synchronization, separate the roles of self and others, infer others' intentions, share intentions with others, and cooperate in solving problems. Such experiences may help in developing the competence to share intentions with others, which can be generalized to everyday life. However, no quantitative studies based on actual behaviors of both cognitive activities and human movements in school education have been conducted. Therefore, this study analyzed and clarified the relationship between physical and cognitive tasks that require the sharing of intentions with others to develop competence in sharing intentions with others through human movement.

Tasks and Hypotheses for the Study

In this study, we observed two types of pair activities during physical education (PE) and mathematics lessons. In the PE lesson, the task was a 3-on-2 tag game where two-partner defenders prevented three attackers from passing through to reach the goal line. In the math lessons, to understand new mathematical concepts, two children were required to discuss the concepts with a partner. Both tasks required sharing the task goals and inferring the intentions of others during pair activities. In the tag game, to prevent the attackers from passing through, the defender must chase the attackers as an individual behavior (**Figures 1A-a1**) and coordinate with his/her partner's movement and infer and share the partner's attention to the attackers' movement as a pair behavior (**Figures 1A-a2**). In the mathematical discussion, two children had to express their own thoughts as an individual behavior (**Figures 1B-b1**) and infer the other's state of understanding as a pair behavior (**Figures 1B-b2**). It is predicted that the individual and pair behaviors would be reciprocally related because the task constraints in the two tasks are similar.

In the tag games, if the two-partner defenders share the task goal, they would move side by side to prevent the attackers from passing through. Therefore, the individual movement distance of the defender would be shortened in order to defend effectively, and the interpersonal distance between the two defenders would remain at a consistent length. Hence, in the physical task, we observed that the defenders' movements and analyzed the distance each defender traveled as an individual behavior and the interpersonal distance between the two defenders as a pair behavior. In the math discussion, if a pair shared a task goal, we would see a responsive behavior toward the other. Specifically, an individual would make utterances to confirm (1) the listener's understanding of their own thoughts, (2) the others' thoughts, and (3) the listener's attention to the object of the pair activity. In addition, a pair would show many role changes while sharing intentions with each other. Therefore, in the cognitive task, we observed the talking and listening behaviors during the pair activities and analyzed the content of the utterances at that time and the gaze direction of the listener as an individual behavior, and the frequency of the role changes as a pair behavior. In learning science for collaborative problem-solving ability, the analysis focused on conversational style and conceptual level as assessment for the deepening of understanding. Given that the conceptual level is domain-specific, this study focused only on conversational forms.

The study's hypotheses are summarized as follows.

1. The constraint of the task is that each person should not perform the task alone (**Figures 1a1,b1**); rather, two people should share the task (**Figures 1a2,b2**). Because of this constraint, individual and pair behaviors interact with each other.

   1.1 In the physical task, individual movement efficiency and interpersonal distance are positively correlated.
   1.2 In the cognitive task, individual responsive behaviors and the frequency of role changes are positively correlated.

2. Because the constraints and structure of the physical and cognitive tasks are similar, individual and pair behaviors in the two tasks are positively correlated.

MATERIALS AND METHODS

Participants

The participants were 32 third-grade elementary school children (10 boys and 22 girls), all of whom were in the same class. Their pair activities with the same partner were observed three times in one PE lesson and two math lessons. In the PE lesson, the task was a 3-on-2 tag game, for which the first lesson of six lessons was observed as one unit. In the math lessons, the task was to understand the concept of partitive division through pair

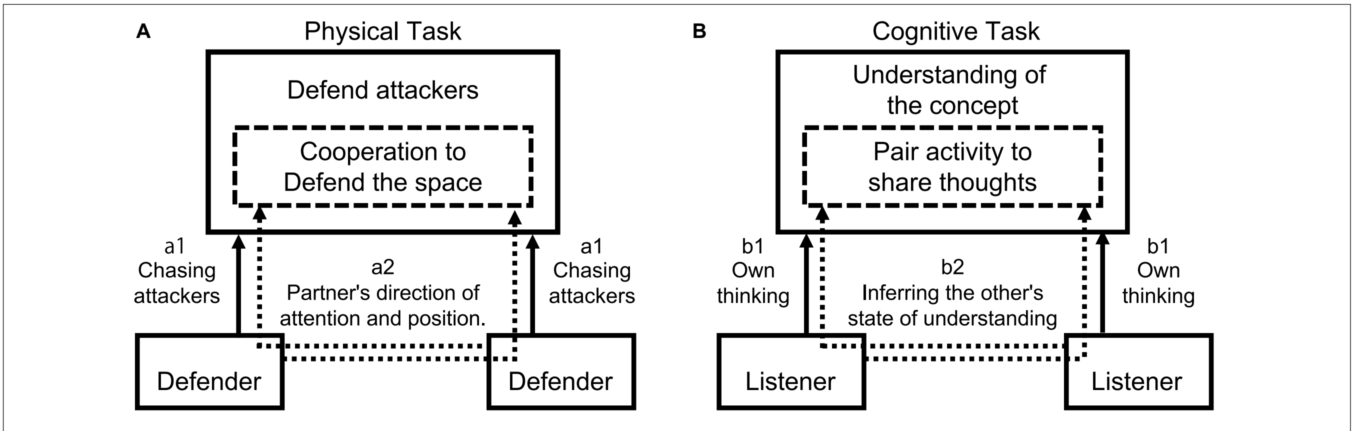

FIGURE 1 | Task structure of physical task **(A)** and cognitive task **(B)**. Panel **(A)** illustrates the task structure of a 3-on-2 tag game. The defender is required to defend the space in a coordinated way by chasing the attacker (a1) and inferring and sharing the partner's attention to the attackers' movement (a2). Panel **(B)** illustrates the task structure of the pair activity in the math class. Given that the pair activity task is to share each other's thoughts, the children need to express their thoughts (b1) and infer the other's state of understanding (b2). Solid lines denote individual behaviors and dotted lines denote pair behaviors.

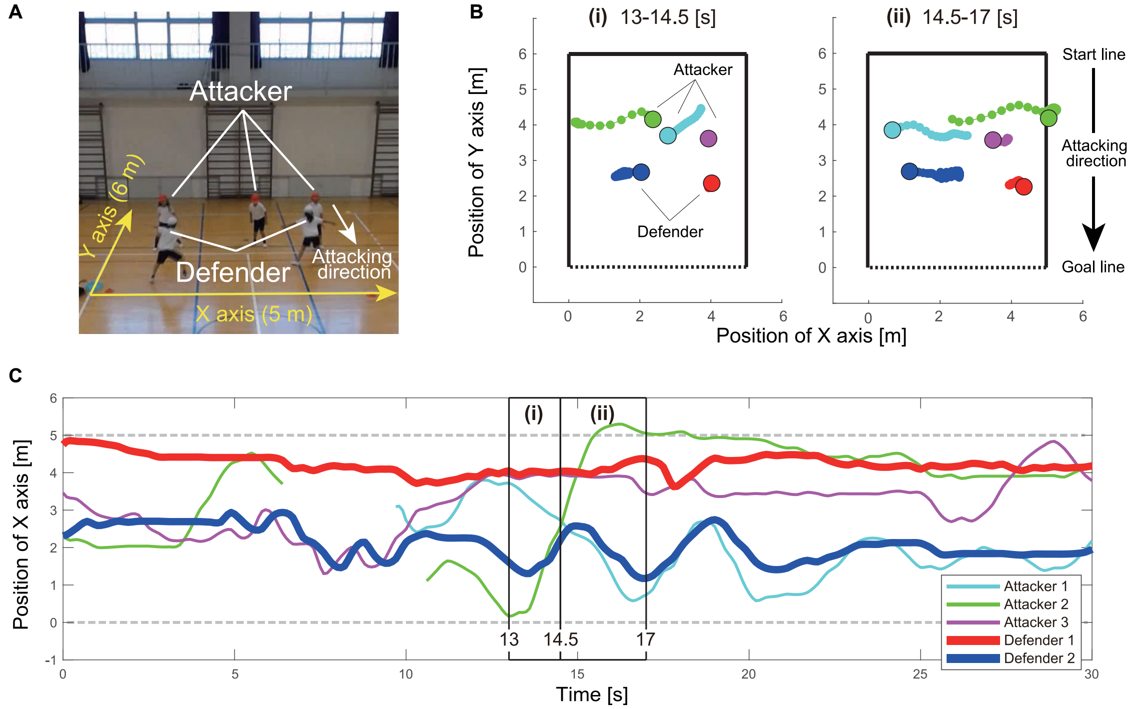

FIGURE 2 | Examples of recording and analysis of physical tasks. Panel **(A)** illustrates a part of the recording view for the physical task, 3-on-2 tag game, and the definition of the X-Y axis. Panel **(B)** provides examples of movements of two defenders (red and blue) and three attackers (cyan, green, and magenta) on the court corresponding to the two boxes (i,ii) in panel **(C)**. Panel **(C)** shows the time series in the position of the X-axis for the two defenders and three attackers. The red and blue bolded lines represent the two defenders and the cyan, green, and magenta shin lines represent the three attackers. The time when the shin line is broken is when the attacker reaches the goal line or is touched by the defender. The distance between the red and blue lines is calculated as X_IPD.

activities. The first math lesson was held before the first 3-on-2 tag game lesson, and the second math lesson was held after the third tag game lesson was observed. Of the 32 children, 16 children of 8 groups were selected for analysis; the other 16 children were excluded from the analysis as explained in the following. Two children were absent from both PE and math lessons and six children joined two groups of three children in the math class; therefore, these children were excluded. One pair (two children), including one child who observed the physical education class because of injury, and another pair (two children) who played only one game because they could not complete the game for lack of understanding of the rules and roles were also excluded. We also excluded two pairs (four children) who were unable to record their utterances for two lessons of the math classes.

Task

Physical Task: 3-on-2 Tag Game

For the 3-on-2 tag game, the goal was for two defenders to prevent three attackers from passing through to the goal line of a 6 m long by 5 m wide court (**Figure 2A**). An attacker scored one point if he/she could pass through the goal line without touching the defender. After scoring a goal, he/she should return to the start line and start all over. If the attacker is touched in court by the defender, they return to the start line and start all over. The task of the defenders was to prevent the attackers from passing through as much as possible. The teacher had informed the children of the rules and roles of the attacker and defender before the game started. Then, the 32 children were divided into three groups of six children and two groups of seven children for each court. Each group played 11 games (55 games in total) with the children switching roles as defenders and attackers. The playing time for each game was approximately 60 s. In the group of six children, when the children played the role of defender, they partnered with the same child in all the cases. In the group of seven children, two pairs of four children partnered with the same children when they played the role of a defender in all the games. The remaining three children partnered with other children as defenders. These pairs were excluded from the analysis.

Cognitive Task: Understanding Partitive Division in Math

The cognitive task was to understand the concept of partitive division through cooperative discussion between two children in the math classes. The two math lessons dealt with partitive division, and the children were asked one basic question and one applied question in each lesson. At first, each child worked on the basic problem on their own sheets by themselves, and then some children presented their own answers to all children. Subsequently, each pair discussed their presentations and understood and confirmed the solution method. In the basic task of the first lesson, Child A presented his solving method to all children approximately 15 min after the first question was presented, and a pair activity to confirm his solving method was carried out for 180 s. In the application task of the first lesson, a pair activity to discuss the solution method with each other was carried out for 162 s approximately 10 min after the applied question was presented. In the basic task of the second lesson, Child B presented his solving method to all children approximately 20 min after the first problem was presented, and a pair activity to confirm this was carried out for 119 s. In the application task of the second lesson, Child C presented his answer to all children approximately 16 min after the problem was presented, and a pair activity to discuss his solving method was carried out for 65 s. Only the same eight pairs as in the physical task were analyzed for the four pairs of activities.

Analysis

Tag Game

All the tag games played in the five courts were recorded using two webcams (Logitech C922 Pro Stream Webcam, Japan) from the second floor of the gymnasium. One webcam recorded the tag games on three courts, and the other, on two courts. We analyzed only eight fixed pairs. Five pairs played four games each, and three pairs played three games each. The positions of three attackers and two defenders in 29 games were digitized at 10 Hz in each game using motion analysis software (Frame Dias V, DHK, Japan), and transformed to the actual coordinates using a two-dimensional direct linear transformation method. The player's position was defined as the midpoint between both feet. The X-axis was set directly along the goal line of the court, and the Y-axis was set perpendicular to the X-axis directed along the sideline of the court toward the reverse of the attack's direction (**Figure 2A**). **Figure 2B** shows an example of the movements of two defenders (red and blue) and three attackers (cyan, green, and magenta) on the court corresponding to the two boxes (i and ii) in **Figure 2C**.

Pair Activity in Math

In math lessons, we recorded the behavior of pair activities using two video cameras (Panasonic HC-VX990M, Japan) and a webcam (Logitech C922 Pro Stream Webcam, Japan) to observe all pairs in the class (**Figure 3A**). In addition, utterances in pair activities were recorded using 14 IC voice recorders (Olympus VN-541PC, Japan) for each pair. We then used video editing software (EDUIS9, Grass Valley, Canada) to synchronize the video recording of the camcorder with the audio recording of the IC recorder. Based on the recordings, we analyzed the utterance content and gaze direction every second (**Figures 3B,C**).

Dependent Variables

Table 1 provides the study's overview and dependent variables. The dependent variables in the tag game were the efficiency of individual movement and the interpersonal distance on the X-axis for individual and pair activities, respectively. In the Math classes, the responsive behavior, consisting of responsive utterances and active listening, was the dependent variable for individual activities, and the role change was the dependent variable for pair activities.

Efficiency of Individual Movement

We calculated the movement distance of each defender in each game, then calculated the mean velocity of each defender, and the reciprocal of the mean velocity was defined as the efficiency of individual movements. Because the game durations differed, the inverse of the mean velocity, which is the time taken to move a distance of 1 m, was considered to represent the efficiency of individual movement. As the movement length decreases, the efficiency of individual movement increases, and vice versa.

Interpersonal Distance as a Pair Behavior

Figure 2C shows the time series of the positions on the X-axis for two defenders and three attackers. As the variable of pair behavior, the average interpersonal distance of the two defenders in the X-axis [X_IPD (m)] direction in each game was calculated. In **Figure 2Bi** and the left box (i) in **Figure 2C**, the blue defender is shown chasing the green attacker; then the blue defender changes to chase the cyan attacker, as shown in **Figure 2Bii** and the right box (ii) in **Figure 2C**. In this case, two defenders are keeping constant interpersonal

TABLE 1 | The study's overview and dependent variables.

		Physical task	Cognitive task
Participants		8 pairs (16 children) of 3rd grade elementary school students	
Task		Defend attackers in the tag game	Pair activity in two math lessons
Analysis		Movements on the court in approximately 60 s × 29 games	Utterances and gaze directions in four pair activities
Dependent variables	Individual	Efficiency of individual movement	Responsive behavior (Responsive utterance and active listening)
	Pair	Interpersonal distance on X-axis	Role change

TABLE 2 | Categories and definitions of utterances.

Category	Definition
Assertive utterance	Independent of the previous context; transmits one's own thoughts and suggestions regarding the task to the partner
Responsive utterance	Inherits the previous context; shows interest and understanding for the partner's utterances, not only regarding the task but also the partner's utterances 1. An utterance in which turn-taking occurs; an individual accepts the partner's utterance, takes over the content, and conveys his/her thoughts to the partners 2. Non-vocabulary word format called "back channel"
Irrelevant utterance	Irrelevant to the task or expresses a refusal to respond to the partner's thoughts

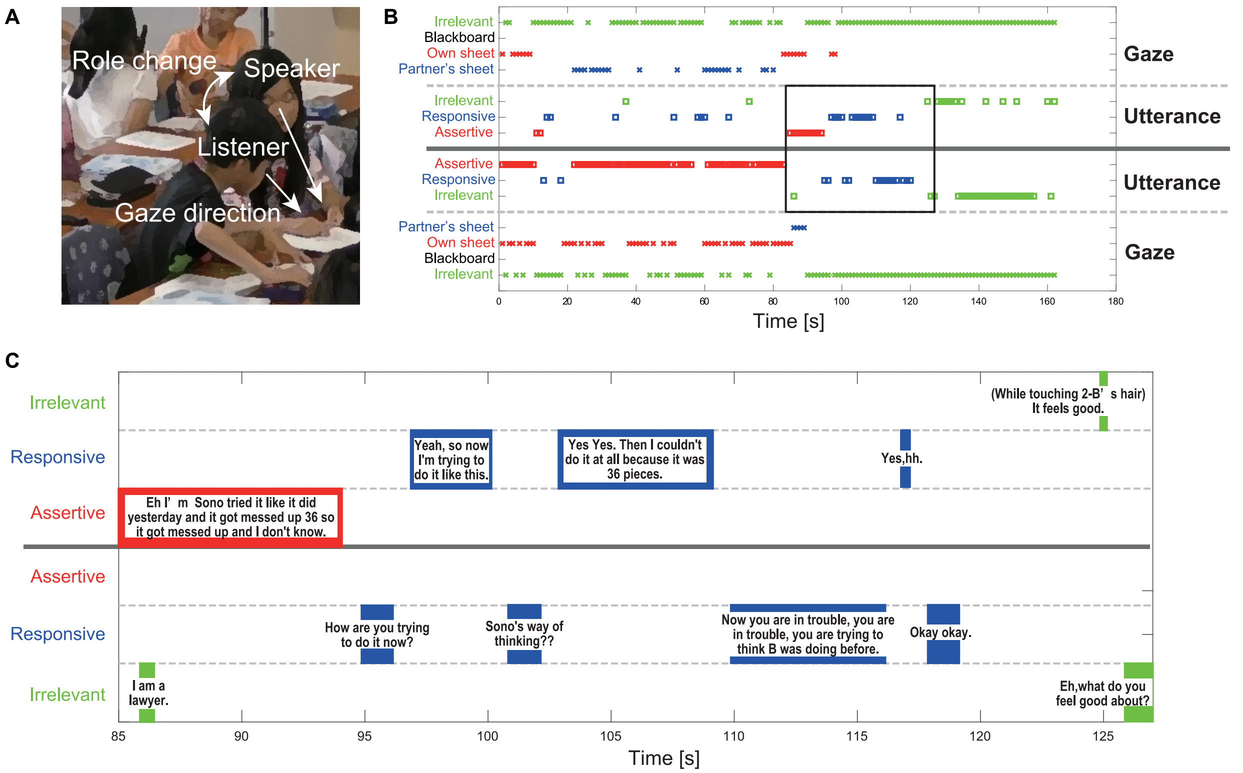

FIGURE 3 | Examples of recording and analysis of cognitive tasks. Panel **(A)** shows a part of the recording view for the cognitive task, which is the understanding of partitive division through pair activity in the math classes. Panel **(B)** illustrates the time series of the four types of gaze directions and three categories of utterances during the pair activity of two children. Panel **(C)** demonstrates three specific categories of utterances during a pair activity between two children corresponding to the box in panel **(B)**.

distance on the X-axis, not changing their positions to the right and left.

Responsive Behavior as Individual Activities

Responsive Utterance

Using utterance content analysis, the degree of shared intention with the partner was evaluated as an individual's responsive utterance during pair activities. The utterance content was classified into the following three categories (**Table 2** and **Figure 3C**). The first is "assertive utterance," which is characterized by transmitting one's own thoughts and suggestions regarding the task to the partner in the pair (**Figures 1B-b1**). An example is the following utterance: "Eh I'm Sono; tried it like it did yesterday and it got messed up 36 so it got messed up and I don't know" (**Figure 3C**, 85–94 s). The second is "responsive utterance" to the partner's utterance, showing interest and understanding not only for the task but also for the partner's utterance (**Figures 1B-b2**). This includes the following two types of "responsive utterances." The first is an utterance in which turn-taking occurs: the individual accepts the partner's utterance, takes over the content, and conveys one's thoughts to the partners (Schegloff and Sacks, 1973). An example is the following utterance: "How are you trying to do it now?" (**Figure 3C**, 95–96 s). The other is a non-vocabulary word format called "back channel" (Yngve, 1970). An example is the following utterance: "Yes,hh" (**Figure 3C**, 117 s). In addition, acts without a voice were considered back channels in agreement with the utterance and counted, such as nodding the head and pointing. The third is "irrelevant utterance," which refers to those that are irrelevant to the task or express refusal to respond to the partner's thoughts. An example is the following utterance: "(While touching 2-B's hair) It feels good" (**Figure 3C**, 124 s). When classifying utterances, we considered not only the meaning of the words but also the context and subtle nuances of the utterance. Taking the sentence "I don't understand" as an example, the child is confused because he/she cannot understand the partner's thoughts immediately. However, if he/she tried to understand it, the sentence was classified as a "responsive utterance." Meanwhile, if he/she gave up on understanding the task or the partner's thoughts, the sentence was classified as an "irrelevant utterance." Based on this classification, we calculated the ratio of "responsive utterance" duration for all three utterance durations for each child to evaluate the degree of intention-sharing with others.

Regarding the classification of utterances, three researchers classified them in the two pair activities independently and then decided on the evaluation criteria after a discussion among the three researchers. Subsequently, one researcher classified the utterances in the other scenes according to the evaluation criteria.

Active Listening

By analyzing the listener's gaze direction, the degree of joint attention or active listening was evaluated as an individual behavior during pair activities. The listeners' gaze direction was classified into four categories: "partner's sheet," "own sheet," "blackboard," and "irrelevant." When the gaze direction was toward the "partner's sheet," "own sheet," and "blackboard," it was judged that joint attention was established between the partners and active listening was performed. The gaze direction toward "own sheet" and "blackboard" were classified as "active listening." In all the scenes, the children looked at the partner's sheet after looking at their own and the blackboard to confirm their thoughts. The gaze direction classified as "irrelevant" included the child looking at the partner's face, other pairs, and so on. Regarding the gaze direction to the partner's face, it was judged that the child was "actively listening" when he/she looked at the partner's face for a moment. However, if the gaze direction to the partner's face continued for a long time, we did not classify it as "active listening" because of the possibility that this signified drifting from the task. Based on this classification, the ratio of "active listening" was calculated by dividing the "active listening" duration by the total time of the four categories of listening.

Responsive Behavior as Individual Activities

Finally, the mean of the ratio of "responsive utterance" and the ratio of "active listening" were used as the "responsive behavior" during pair activities and as an index showing the sharing of intentions with others. For example, in Pair 1, the frequency of "responsive utterance" was 0.32, and the frequency of "active listening" was 0.85. "Responsive behavior" was then calculated as $(0.32 + 0.85)/2 = 0.59$. A high ratio of "responsive behavior" indicates an attempt to share intentions with others as an individual behavior during pair activities.

Role Change as Pair Activities

The frequency of "role change" was calculated as an index of pair behavior. There are two types of role change in conversation. One is "turn taking" (Schegloff and Sacks, 1973), which indicates the initiative of the utterance. The other is "back channel" (Yngve, 1970), which does not change the turn but shows interest and understanding of the other's utterance. It is presumed that the high frequency of role change indicates that the conversation is interactive and that the interest in and the understanding of others' thoughts are high. For the frequency of role change, we defined the average number of role change occurrences by calculating the number of role changes in one 1 s based on the number of role changes in the total speaking time of the pair. A high frequency of role changes indicates more active interactions within pairs.

Statistical Analysis

For the physical task, to test Hypothesis 1.1, Pearson's correlation and Spearman's rank correlation coefficients were calculated to examine the relationship between the efficiency of individual movement as an individual behavior and interpersonal distance on the X-axis (X_IPD) as a pair behavior during the tag game. In this calculation, the mean efficiency of the individual movements in each pair was used. For the cognitive task, to test Hypothesis 1.2, Pearson's and Spearman's rank correlation coefficients were obtained to investigate the relationship between the mean ratio of responsive behavior in each pair as an individual behavior and the frequency of role change as a pair behavior during math lessons. Finally, we investigated the relationship between the behavior of defenders during tag games and pair activities in math lessons. To test Hypothesis 2, we calculated the Pearson's correlation and Spearman's rank correlation coefficients between the efficiency of individual movement during the tag game and the ratio of responsive behavior in math lessons as an individual behavior, and between the defenders' X_IPD during the tag game and frequency of role change in math lessons as pair behaviors. The significance level was set at $P < 0.05$.

Informed Consent

This study was conducted with the approval of the research ethics review committee of the university in accordance with the principles of the Declaration of Helsinki and with the written consent of the managers and teachers at the elementary school. Through the teacher-in-charge, we explained the study purpose and contents, permission for recording, protection of privacy, handling of data, and so on, to the participants and their parents and obtained their written consent.

RESULTS

Defender in the Tag Game

Figure 4A shows the means and standard deviations of the two defenders' X_IPDs (m) for each pair, rearranged in the order in which the pairs showed a longer X_IPD. Pair 1 participated in four games. The X_IPD in the first to the fourth games were 1.85 m, 1.84 m, 1.81 m, and 2.32 m, respectively. The average X_IPD for the four games was 1.95 ± 0.21 m, and Pair 1 showed the longest X_IPD. By contrast, Pair 8 participated in three games; the X_IPD in the first to the third games were 0.94 m, 1.14 m, and 1.52 m, respectively, and the average X_IPD for the three games was 1.20 ± 0.24 m, which was the shortest X_IPD. The average positions and standard deviations of the two defenders in all games in court are shown in **Supplementary Figure 1**. **Supplementary Table 1** shows the average X_IPD for each tag game and the means of the X_IPD for the pairs. **Figure 4B** shows the means and standard deviations of the individual defenders' movement efficiency. The order was arranged according to the order of the X_IPDs for each pair. Child A in pair 7 showed the most efficient movement (2.02 s/m), and Child B in pair 2 showed the worst (0.87 s/m). These results suggest that Child B in Pair 2 moved more than twice as much as Child A in Pair 7. **Supplementary Table 2** shows the individual defenders' movement efficiency for each tag game and the means of the individual and pair movement efficiency. **Figure 4C** shows the relationship between the defender's X_IPDs and the individual efficiency of movement. The results showed a significant Pearson's correlation coefficient ($r = 0.771$, $p = 0.026$) and marginally significant Spearman's rank correlation coefficient ($r = 0.667$, $p = 0.071$). A high positive correlation was found between the X_IPDs of the two defenders as a pair behavior and the individual efficiency of movement in tag games. This means that the pair that maintains a certain distance from the partner has shorter individual movement distances during the game, and vice versa. The results suggest that long interpersonal distance as a pair behavior and short movement distance as an individual behavior interacted with each other, indicating shared task constraints and task goals. This finding supports Hypothesis 1.1.

Pair Activity in Math Lessons

Figure 5A shows the frequency of "role change" in each pair during pair activities, rearranged according to the order in which the pairs showed a longer X_IPD (**Figure 4A**). For Pair 1, a "role change" was observed to occur 9.01 ± 5.74 times per min. **Supplementary Table 3** shows the frequency of role change during each pair activity in the math lessons and the means of the role change for the four pair activities. **Figure 5B** shows the frequency of individual responsive behaviors for each individual during pair activities. **Supplementary Table 4** shows the individual responsive behavior frequency during each pair activity in the math lessons and the means of the individual and pair responsive behaviors. **Figure 5C** shows the relationship between the frequency of "role change" and "responsive behavior." The results showed a marginally significant positive Pearson correlation coefficient ($r = 0.705$, $p = 0.051$) and Spearman rank correlation coefficient ($r = 0.500$, $p = 0.207$). This means that the more frequently "role change" as a pair behavior occurred in each pair, the higher the "responsive behavior" frequency during the utterance duration as individual activities and vice versa. This finding suggests that many role changes in pair activities and individual responsive behaviors would interact and that the pairs had collaborated with each other, and shared task constraints and task goals. This result partially supports Hypothesis 1.2.

Relation Between Movement as a Defender in Tag Games and Pair Activities in Math Lessons

The relationship between individual and pair behaviors in tag games and math lessons was examined. **Figure 6A** shows the relationship between individual efficiency of movement in tag games and the ratio of individual responsive behavior in the pair activity of the math lessons. The results showed a significant positive Pearson's correlation coefficient ($r = 0.657$, $p = 0.005$) and Spearman's rank correlation coefficient ($r = 0.729$, $p = 0.007$). This means that children who showed higher efficiency of individual movement as a defender in the tag games had a higher frequency of "responsive behavior" during pair activities in the math lessons, while children who showed lower efficiency of individual movement in the tag games had a lower frequency of "response action" in the math lessons. In addition, in **Figure 6A**, the values for the two children in the same pair are connected by a line. Interestingly, the slope of the line in six out of the eight pairs was positive. The efficiency of individual movement as a defender in the tag game refers to understanding the task goal, which is how to cooperate with a partner to prevent attackers from passing through the goal line. Meanwhile, the higher "responsive behavior" in the pair activity during math lessons consisted of "responsive utterances" and "active listening." This means that the children who showed higher frequency of "responsive behavior" tried to understand the partner's thoughts. Both behaviors observed in the tag games and math lessons could be regarded as individuals in each pair understanding and sharing each task goal equally.

Figure 6B shows the relationship between the defenders' X_IPDs in the tag games and the frequency of role changes in the pair activities in the math lessons. There was a significant positive Pearson's correlation coefficient ($r = 0.765$, $p = 0.010$) and Spearman's rank correlation coefficient ($r = 0.833$, $p = 0.010$). These results indicate that the pair that maintained a certain distance and prevented attackers from passing through in the tag games frequently performed role changes in the math lessons, and vice versa. This result supports Hypothesis 2. Regardless of the type of task: cognitive or physical, the children could act as pairs according to the task demands because they could share task goals and others' intentions.

DISCUSSION

In this study, the targets of analysis were the movements of two children who shared a task requiring coordination skills in a PE class, and the communication between two children during a pair activity set as collaborative for problem-solving in a math class. We then focused on the relationship between the behaviors of individuals and pairs in each task.

First, a significant positive correlation was found between the X_IPD and the efficiency of the individual movements of the two defenders in the tag game (**Figure 4C**). The game was carried out on a court that was 6 m long and 5 m wide. If two defenders are positioned side by side and the space that the attacker can breakthrough is divided into equal parts, the X_IPD is 2.50 m, and the distance from one defender to the sideline of the court is 1.25 m. Therefore, the three pairs whose X_IPD mean are nearly 2 m adjusted their position and movement according to the position and movement of their partner (Pair 1, 1.96 m; Pair 4, 1.88 m; and Pair 7, 1.93 m). These three pairs also showed higher efficiency for the individual movement distance, as demonstrated by the lateral movements not overlapping, and the movements in the back-and-front positions being small (**Supplementary Figure 1**). The defenders move forward when chasing attackers before they try to pass through, or the defenders move backward when trying to follow the attacker even after the attackers have passed through. These two cases are considered movements that respond to one attacker where the defender tries to catch up only by oneself rather than movements that satisfy the task demands, which prevents pass through *via* collaborative movements.

Previous studies showed that experts could infer others' intentions from their movements, and consequently maintain a constant interpersonal distance between them to achieve their goals in interpersonal sports activities (Yokoyama and Yamamoto, 2011; Kijima et al., 2012;

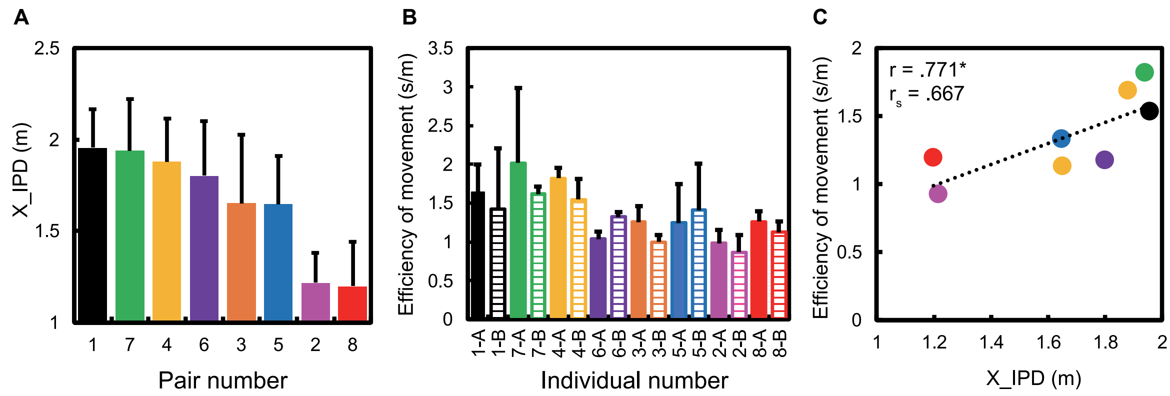

FIGURE 4 | Results of the tag games. Panel **(A)** shows the mean and standard deviations of X_IPDs in each pair. Panel **(B)** shows the mean and standard deviations of the efficiencies of individual movement for each child. Panel **(C)** shows the relationship between X_IPD and the mean efficiency of individual movement for each pair. *P < 0.05.

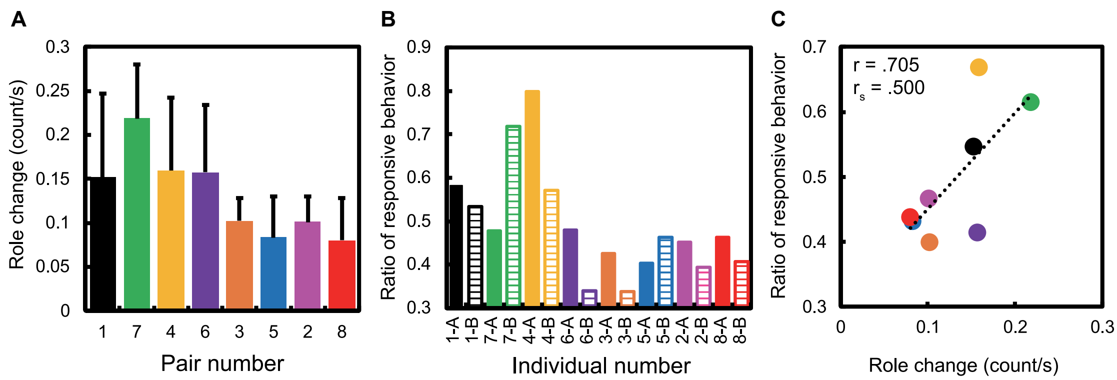

FIGURE 5 | Results of the pair activities in the math classes. Panel **(A)** illustrates the mean frequencies and standard deviations of the role changes for each pair. Panel **(B)** shows the ratio of the individual responsive behavior for each child. Panel **(C)** shows the relationship between role change and responsive behavior.

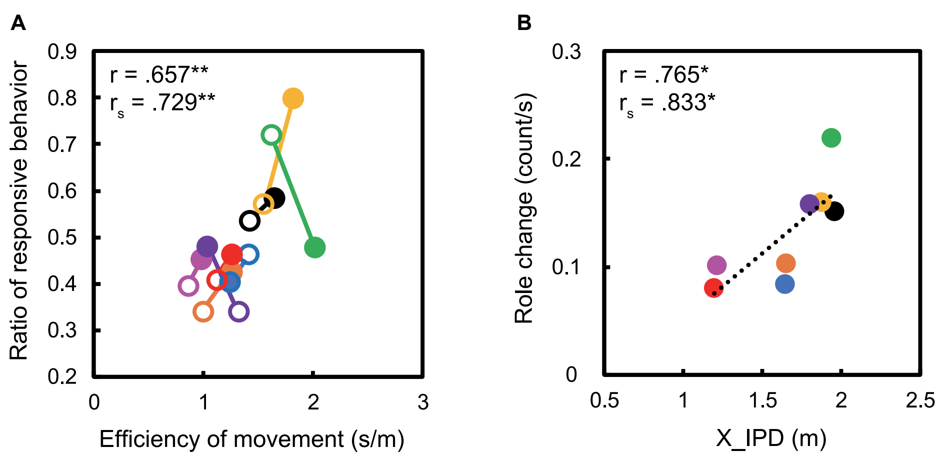

FIGURE 6 | Relationship of the individual and pair behavior indicators in the physical task with those in the cognitive task. Panel **(A)** shows the relationship between the individual behavior indicator in the 3-on-2 tag game and the pair activities in the math classes. The horizontal axis shows the time it takes to move 1 m of an individual's efficiency of movement in the 3-on-2 tag game. The vertical axis shows the ratio of responsive behavior in the pair activity. Panel **(B)** shows the relationship between the pair behavior indicator in the 3-on-2 tag game and the pair activities in the math classes. The horizontal axis shows the X_IPD of the game, and the vertical axis shows the role change in the pair activity. *P < 0.05, **P < 0.01.

Yokoyama et al., 2018). Meanwhile, this study showed that children with both shorter movement distances and constant X_IPD could understand the not-to-lose strategy in tag games and perceive the movement of teammates and adjust their relative positions accordingly. The results suggest that they could share task goals and others' intentions and consequently, could move while paying attention to the position and movement of each other to achieve the task.

Next, in the math class pair activity, a marginally significant positive correlation was found between responsive behavior and role change (**Figure 5C**). To share and understand each other's thoughts in pair activities, the speaker must construct an utterance such that the listener can understand it, rather than unilaterally communicating his or her own thoughts (Goodwin, 1999). Meanwhile, the listener has to listen to the speaker's thoughts by jointly paying attention to the same subject as the speaker's. It is necessary to prepare to continue the pair activity through "turn-taking" (Schegloff and Sacks, 1973) and "back channel" (Yngve, 1970). Pairs with low frequencies of role change and low-responsive behavior had longer utterance durations (see **Supplementary Figure 2**). Furthermore, in those pairs, the utterance content included more "argument utterance" and "irrelevant utterance" that showed one's thoughts and suggestions (**Figure 5C**). These results suggest that such pair activities were not activities to share thoughts with each other or develop thoughts through discussion, but to express one's selfish way of thinking on a task. Meanwhile, pairs that showed high frequencies of role change and responsive behavior had a shorter utterance duration in a single utterance. The results also showed that the utterances that responded to the previous content of the partner and the back channel showing interest and understanding in the partner's utterance were higher. The back channel signifies the listener's effort to pay attention to the speakers jointly and is triggered by the speaker's final particle, and both the final particle and the back channel produce a stable rhythm of conversation (Clancy et al., 1996). In addition, through the back channel, two people perform complementary roles, each depending on the needs of the task at hand (Fusaroli et al., 2013). In other words, pairs with higher frequencies of role change and responsive behavior can be regarded as signifying pair activities in which thoughts are shared with each other. Therefore, a speaker–listener interaction can be considered as an attempt to understand the task goal and share intentions if it is being carried out while guessing both the partner's thoughts and the partner's understanding of one's own thoughts. This suggests that responsive behavior as an individual behavior promotes role change as a pair behavior in cognitive tasks, and vice versa.

Finally, a significant positive correlation was found between the defender's efficiency of individual movement in the tag game and the responsive behavior in the math class pair activity (**Figure 6A**). A significant positive correlation was also found between the interpersonal distances between defenders in the tag game and the frequency of role change in the math class pair activity (**Figure 6B**). Children and pairs who could pay attention to the movement of both partners' defenders and attackers to achieve the task in the tag game could also follow the partner's utterance and take over the utterance content of the partner in the math classes. Meanwhile, children and pairs who tended to chase attackers according to their own selfish intention without being influenced by others' defenders in the tag games unilaterally conveyed their thoughts in the math classes. Moreover, there was a tendency not to listen to others' thoughts carefully.

Our research hypotheses were supported, suggesting that there is a common fundamental competence in sharing intentions with others. Despite the difference in task type: physical and cognitive, the relationship between the individual behavior and the behavior of the two in each task was found in the "joint attentional scene" and the "understanding [of] communicative intentions" for sharing the task goals and intentions of others (Tomasello, 1999). The defenders of a tag game are required to perceive that it is a game, that is, a joint attentional scene where two people cooperate to prevent attackers. In addition, defenders need an "understanding [of the] communicative intentions" to share who defends which attackers. In a pair activity in math classes, children need to recognize that the activity is about perceiving each other's information and sharing thoughts about the current problem. In addition, children are required to "understand communicative intentions" to infer how others understand their own thoughts. In other words, the two types of tasks in this study need to be perceived not only as the task itself but also as information about the behaviors of the "other" for the task. It is also necessary to understand the intentions of others regarding their state of attention and what they perceive themselves. Therefore, although the tasks in this study differ by type (i.e., physical vs. cognitive), the task structure is similar in that both require "planned coordination" (Knoblich et al., 2011) with others. As such, the correlation between the two tasks on an individual and a pair behavior level showed a common competence in sharing task goals and intentions, regardless of task type.

In this study, we showed the common competence between physical tasks in PE classes and cognitive tasks in math classes, but we could not describe the causal relationship between them. However, if the sharing of intentions with others is based on the perceptual-motor system, there is a possibility that such competence can be cultivated by performing tasks using the perceptual-motor system. Previous studies have shown that exercise promotes social cognition (e.g., Reddish et al., 2013; Cirelli et al., 2016) and that sharing intentions with others is necessary for physically planned coordination tasks with others (Yokoyama and Yamamoto, 2011; Kijima et al., 2012; Yokoyama et al., 2018). For the 3-on-2 tag game (the physical task in this study), coordinated movement is essential to achieve cooperation with others, and the process of cooperation is directly related to the results. Children develop scientific thought processes while exploring the world, for instance, the use of Bayesian inference methods to infer the cause from results (Gopnik, 2012; Gopnik et al., 2017). In fact, when the games were repeated, in the cases of Pairs 5, 6, 7, and 8, the two defenders were positioned side-by-side from back-and-front positioning, and Pair 2 also decreased back-and-front movement (see **Supplementary Figure 1**). This suggests that if sharing tasks and intentions with others is designed as a task constraint in physical tasks, participants may repeatedly search for causes of point loss. Meanwhile, the cognitive task of understanding certain concepts in mathematics might not clarify whether a learner could understand it. It was argued that in the cognitive task, the repeated experience of searching for causes would be difficult, and the perceptual-motor system could not be used because of the relatively stable environment.

In other words, the results suggest the possibility of a new approach to cultivating the common fundamental competence of sharing task goals and intentions with others through human movement, especially in elementary school education, where the sensorimotor system is not sufficiently developed. In the future, empirical research should examine whether sharing tasks and intentions with others through physical exercise influences collaborative cognitive activities.

In this study, the interaction between individual and pair behavior was clarified, but the analysis was limited to 8 pairs of 16 participants. Therefore, it is necessary to increase the number of cases to confirm the results. Moreover, we estimated the shared intentions through behavioral observation. To evaluate the shared intentions more appropriately other perspectives are needed; this can be achieved by using qualitative methods such as interviews or questionnaire surveys of children and teachers. Furthermore, the relationship between the two individuals, that is, leader–follower relationship, should be analyzed. Studies have suggested that behavioral characteristics in daily life affect cooperative relationships (Schmidt et al., 1994; Fitzpatrick et al., 2016; Mukai et al., 2018). It is also a future task to investigate in detail the kind of interaction that occurs between the two parties and how these activities are developed.

CONCLUSION

In conclusion, children and their pair characterized as moving freely according to their own selfish intention in the tag games saw the pair activity in math classes as a "scene to convey their thoughts." Meanwhile, those who could move while paying attention to the position and movement of each other in order to achieve the task in the tag game regarded the pair activity in the math classes as a scene to share each other's thoughts and engage in behaviors to listen to each other's thoughts. This finding suggests that the sharing of intentions with others is a common fundamental competence in both physical and cognitive tasks for solving the task at hand cooperatively. A human being represents a complex system. The human movement of others cannot be understood entirely in the same way as their intentions. However, the task constraints of joint action in PE lead to an understanding of the task goals and exploration of the solution through trial and error. These experiences in PE might be generalized to cognitive tasks to cultivate the competence in sharing intentions with others.

DATA AVAILABILITY STATEMENT

The original datasets presented in this study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Research Promotion Committee, Faculty of Education, Mie University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

TK, KY, and YY conceived and designed the task and analyzed the data. TK recorded the lessons. All authors contributed to the study and approved the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.863267/full#supplementary-material

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