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Using wearable sensors to explore schoolyard interactions of mainstreamed deaf and hard-of-hearing preadolescents

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Abstract

Social participation in school, including schoolyard interactions, is considered important for all aspects of child development. Students with disabilities, such as those who are deaf and hard-of-hearing, are at risk of experiencing inaccessibility and social exclusion in mainstream classes, yet this has been hard researched in the schoolyard context. We exploratively compared preadolescents (M = 10.48, SD = .93) with (N = 8) and without (N = 207) hearing loss in their continuous schoolyard interactions during 21 recess assessments, using proximity sensors and field observations, alongside measurements of peer acceptance, friendships and sense of connectedness, based on peer nominations and self-reports. Deaf and hard-of-hearing preadolescents spent less time interacting in the schoolyard, a trend which was stable throughout recess. Deaf and hard-of-hearing students interacted with the same number of partners as their classmates, but posthoc analyses suggest that towards the end of long recess periods they had a sharper drop in the number of their interaction partners. Field observations suggest that deaf and hard-of-hearing preadolescents who were socially active became more isolated the longer the break lasted, and that physical proximity did not necessarily indicate positive interactions. Findings underscore the importance of using multimethod designs that assess various dimensions of social participation and account for the temporal dynamics of recess interactions. Proximity sensors, combined with qualitative observations, enabled to detect social difficulties not detected by more traditional measures, hence valuable for social inclusion research and interventions.

KEYWORDS
deaf and hard-of-hearing, mainstream, proximity sensors, recess, schoolyard, social inclusion

1 | INTRODUCTION

During recess, the schoolyard is where social relationships develop and strengthen, where children practice their social and emotional skills through child-led free play (McNamara et al., 2017). Engagement in schoolyard interactions is positively linked with children's social competence (Veiga, de Leng, et al., 2017) and is considered crucial for children's social, emotional, and academic development (Jarvis et al., 2014; Murray & Ramstetter, 2013). However, many children also experience loneliness and social exclusion during recess (McNamara, 2017). For children and adolescents who are deaf or hard-of-hearing (DHH)[1] and study in mainstream schools, the schoolyard can be an environment where they are at risk of facing communication difficulties, social rejection, and bullying (Brunnberg, 2005). While there is research on the social inclusion of DHH children and adolescents in mainstream schools, there is only limited number of studies on their participation in schoolyard activities. This study is the first to apply sensing technology to measure schoolyard interactions of preadolescents with and without hearing loss, together with more traditional measures of peer nominations, self-reports, and qualitative field observations.

In many countries worldwide, the majority of DHH students are individually integrated in mainstream classes due to inclusive legislation, changes in educational policies, and medical and technological advances (Paatsch & Toe, 2020). Social inclusion of students with disabilities in mainstream schools has been researched along four dimensions: peer acceptance, students' perceptions of their social acceptance, the presence of positive social interactions between students with and without disabilities, and the presence of positive social relationships or friendships (review by Koster et al., 2009). Like students with various types of disabilities (Koster et al., 2010; reviews by Garrote et al., 2017 and Raedemaker et al., 2020), students who are DHH are at substantial risk of experiencing difficulties in all these dimensions of social inclusion. Self-perception of social inclusion, communication barriers, feelings of loneliness, lack of peer acceptance, bullying and stigma were reported both retrospectively by DHH young adults (Dalton, 2013; Eichengreen et al., 2016; Oliva, 2007), and by DHH students studying in mainstream educational settings (Edmondson & Howe, 2019; Punch & Hyde, 2011; Zaidman-Zait & Dotan, 2017). Furthermore, it has been suggested that these experiences, when accumulated, may lead to long-term traumatic emotional costs (Eichengreen et al., 2016). Lack of peer acceptance was also found in studies based on peer-ratings or sociometric nominations (Nunes et al., 2001; Wolters et al., 2014). In addition, there is evidence suggesting that compared to hearing peers, DHH students have fewer friendships (Nunes et al., 2001) or that their friendships exhibit fewer positive aspects (Rieffe et al., 2018). Finally, preschool and primary school DHH students display fewer social interactions compared to their classmates, and their initiations for interactions are often ignored by hearing peers (Martin et al., 2010; review by Xie et al., 2014). Researchers suggested that social inclusion in mainstream settings may be moderated by factors related to the DHH child, including the presence of additional disabilities (Olsson et al., 2018), sex (with DHH boys being less accepted by classmates; Wolters et al., 2011), factors related to communication skills such as age of cochlear implantation or speech intelligibility (Schorr, 2006; Most, 2007; review by Batten et al., 2014), social behaviors (Wolters et al., 2014), and pragmatic skills (Paatsch & Toe, 2020; Zaidman-Zait & Most, 2020). At the same time, researchers increasingly acknowledge the role of aspects in the school environment in promoting or hindering inclusion, such as peer rejection (Eichengreen, van Rooijen et al., 2023; Xie et al., 2014), or inaccessible features of the listening environment (Krijger et al., 2020).

For children and adolescents who are DHH, the schoolyard environment can be highly inaccessible in terms of acoustics and activities. It is difficult to hear or follow lip-reading in crowded and dynamic group settings, where many children are moving in a single, often very noisy, space. To date, only two studies have examined the social interactions of DHH children in the schoolyard, using video observations. Brunnberg (2005) has examined schoolyard behaviors of hard-of-hearing (HH) students (ages 7–14) who studied in special classes located in a mainstream school before and after they moved to a special school due to municipal considerations. Her findings indicated that in mainstream settings HH students were socially excluded by hearing peers, played mainly with other HH peers, and played mostly in the periphery of the schoolyard or stayed at look-out places. After moving to a special school these students were observed as socially included by deaf peers and mostly playing in the central interaction areas of the schoolyard. Recently, Da Silva and colleagues (2022) video-analyzed schoolyard behaviors of DHH preschoolers who were individually mainstreamed in hearing classes. In their study, DHH preschoolers were observed playing and communicating with hearing peers most of recess time. Still, when compared to hearing peers, DHH preschoolers presented fewer social interactions and more nonsocial behaviors, particularly onlooking and solitary activities.

Alongside the important insights gained from these studies, more research is needed on schoolyard behaviors of youth with and without hearing loss, particularly among preadolescents, as social acceptance by the peer group becomes increasingly important for socio-emotional development during this age-period (Crone & Dahl, 2012; Morrow et al., 2019). Furthermore, due to their resource-consuming nature, observations can inform us only on selected fractions of recess time. During the last decade, a growing number of studies have applied wearable proximity sensors to measure group dynamics in the schoolyard, producing big data extracted continuously every second throughout recess (e.g., Eichengreen, Tsou et al., 2023; Heravi et al., 2018; Stehlé et al., 2011; Veiga, Ketelaar, et al., 2017). Such data allow for detection and comparison of simultaneous interactions of multiple children, as opposed to live or video observations which often capture the detailed behavior of one child or a dyad (Review by Horn et al., 2024). The current study innovatively utilizes such sensing technology to measure social interactions of DHH preadolescents in mainstream schoolyard settings, allowing for more nuanced understanding of multiple group interactions. In addition, research on social inclusion of students with disabilities, mostly students with ASD, intellectual or developmental disabilities, suggested that there may be gaps between different dimensions of social inclusion, for example, between low peer acceptance and few interactions and relatively positive social self-perception (review by Garrote et al., 2017). Most studies conducted with DHH students at mainstream education showed difficulties in all four dimensions of inclusion (e.g., review by Wolters et al., 2014; Xie et al., 2014), yet the number of experimental studies is limited in this field, and they focused on varied age-groups and on different dimensions each. In the current study we attempted at combined exploration of social inclusion by including, alongside schoolyard interactions, more traditional social measures of peer acceptance, mutual friendships and self-reported of sense of connectedness, integrated with qualitative field observations. Further, as noise and communication difficulties may exert cumulative effects such as listening-related fatigue (Bess et al., 2020), we were interested in possible differences between DHH and hearing preadolescents in their interaction patterns across time. While previous studies, using either observations or sensors, considered recess time as a single unit, this study uniquely applied a longitudinal framework to examine the temporal dimension of changes in behavioral patterns.

2 | THE PRESENT STUDY

The first goal of this study was to examine to what extent preadolescents who are DHH participate socially in their schoolyard environment, compared to hearing peers, focusing on their social interactions during recess. We measured the time they spent in interactions and the number of different partners they interacted with during recess in their schoolyard, using proximity-sensing technology, that is, Radio Frequency Identification Devices (RFID). RFID allowed us to continuously measure preadolescents' social interactions with their peers throughout each recess session, objectively and without disruption to their natural behaviors (Nasri et al., 2022; Veiga & Rieffe, 2018), and thus enabled a further understanding of the social dynamics experienced by DHH preadolescents in school. As there were no previous studies based on sensor data, we based our hypothesis on previous observation studies (Brunnberg, 2005; Da Silva et al., 2022), expecting DHH students to spend less time in interactions, with fewer number of partners. Given that this study is the first to use this multimethod approach, we also explored the stability of the sensor data across multiple assessments per schoolyard, and the associations between schoolyard interactions and other measures of social participation as follows.

Next, we compared DHH and hearing students in other dimensions of social participation, including peer acceptance, friendships and self-perception of one's social situation. Peer acceptance was measured by the number of friendship nominations each student received from classmates; presence of friendships by the number of mutual friendship nominations; and self-perception of one's social situation by self-reported sense of connectedness in the context of group integration and in the context of peer intimacy. We expected the DHH students to receive fewer nominations from their classmates, have fewer friendships and feel less connected to their classmates compared to their peers, both in the group context and in the context of peer-intimacy.

Finally, we applied a longitudinal framework to examine whether and how DHH students differ from their hearing peers in patterns of schoolyard social interactions over time. We selected one long recess per class for the comparison. Currently, there is a lack of research on the more nuanced aspects of social dynamics of school interactions (Raedemaker et al., 2020). In the case of students who are DHH the time dimension may be particularly significant as accumulation of noise may lead to listening-related fatigue (Bess et al., 2020). This study attempts to fill in this gap by examining trajectory of interaction patterns over time. To achieve a fuller insight into schoolyard dynamics, we combined sensor data with qualitative observations for each selected recess. Given the lack of prior research that would allow us to anticipate more specific patterns of findings, no specific patterns of findings were hypothesized.

3 | METHOD

3.1 | Participants

Participants were eight DHH and 207 typically hearing Dutch primary-school students (age: *mean* = 10.48, *SD* = .93; *range* = 8.48–13.30), 49.8% of whom were males. In the Netherlands, most schools have two recess breaks during the school day. One recess is usually shorter, lasting around 15 min, while the other is longer, with approximately 15 min for lunch followed by 15–30 min of play. Students are expected to spend the recess in the schoolyard, unless weather conditions prohibit outdoor activities. In the Netherlands, inclusive education policies underwent significant changes following the "Inclusive Education" (*Passend Onderwijs*) Act in 2014. This legislation mandates that all schools are responsible for providing a suitable learning environment for every child. As a result, the majority of DHH children are now integrated individually into mainstream classes (van der Straaten et al., 2021). The eight DHH students in our study were all individually integrated (i.e., being the only students who were DHH in their classes) across seven different schools. We included one class (i.e., Class 5, see Table 1) without DHH students because they shared the same schoolyard and played together with a class participating in the current study, as reported by their teachers. Including this class enhanced the ecological validity of the interactions observed in class 4 by assessing them alongside their schoolyard peers. All other classes, including those belonging to the same schools, were not assessed together. One of the DHH students was tested again 1 year later for another project (Eichengreen, van Rooijen et al., 2023), and was in a different class (i.e., Class 7) at this second time point. This student remained in the same grade a year later, that is,

TABLE 1 Consent rates and missing data.

School	Class	*N* students	Consent rate	*N* peer nominations	*N* self-reports (% missing)	*N* sensors (% missing)
A	1	27	81%	22	20 (9%)	20 (9%)
B	2	30	97%	29	29	28 (3%)
B	3	27	96%	26	26	26
C	4	28	96%	27	27	20 (26%)
C	5	13	100%	13	13	12 (7%)
D	6	25	76%	19	19	19
D	7	27	92%	24	_	20 (16%)
E	8	18	83%	15	15	15
F	9	22	77%	17	17	17
G	10	26	92%	24	24	23 (4%)

Note: Classes 4 and 5 were attending together the schoolyard. Class 4 had one DHH student, class 5 had none. The same DHH student from class 6 participated in class 7 (measured 1 year later). This class was not included in the comparison between DHH and hearing students.

studied with younger students, to support his socio-emotional development. The data from Class 7 was included in this study to strengthen the sample size when examining correlations between sensor data and peer nominations (class 7 filled out different self-reports as part of another project and therefore their self-reports could not be included). While the time gap and change of classmates contributed meaningful data to the correlations, the data from class 7 were not further included in the comparison between DHH and hearing students to keep a single representation of all DHH students in the data. In total, ten different classes participated in this study, each class containing on average 22 students (*range* = 13–29).

All students first filled out peer nominations ($N = 216$), and except for one class (i.e., Class 7) also filled out the same self-reports ($N = 190$). Next, students were assessed at the schoolyard with wearable sensors ($N = 200$) between one to four assessments, resulting in 21 schoolyard recess assessments in total. For the recess of six classes, there were children at the schoolyard from other classes who were not included in the final sample of this study. Some of these pupils and their parents gave consent to wear the sensors, and thus contributed to the interaction counts of the participating pupils. Table 1 summarizes the consent rates, number of students and missing data per each participating class. Reasons for missing sensor data were misfunction of badges or loss of badges by students. The number and duration of assessments are presented in Table 2. Table 3 summarizes details related to the hearing loss of the DHH participants.

3.2 | Materials

3.2.1 | Schoolyard interactions

Time spent in social interactions. The time students spent in social interactions at the schoolyard was measured by computing per student a percentage score of the time the student spent in social interactions, divided by the total time the student was detected during recess. Time in interactions was measured by wearable proximity sensors, using OpenBeacon Radio Frequency Identification Devices (RFID) (Cattuto et al., 2010). RFID sensor badges utilize low-energy Bluetooth technology to identify other badges at an approximate orientation range of 30–65 degrees and within an approximate distance of up to 1.5 meters (Cattuto et al., 2010; Elmer et al., 2019). The use of the RFID technology has been validated previously with both adult and child populations. Social contacts detected by the RFID

TABLE 2 Number and duration of schoolyard assessments per class.

School	Class	Morning I	Lunch I	Morning II	Lunch II	Total N assessments
A	1	23 min obs	29 min			2
B	2		16 min	29 min obs	13 min	3
B	3		25 min obs	22 min	12 min	3
C	4	12 min obs				1
C	5	12 min				1
D	6		19 min	37 min obs	26 min	3
D	7		25 min			1
E	8		20 min obs			1
F	9	15 min	21 min obs	17 min	24 min	4
G	10	36 min obs		23 min		2
Total						21

Note: obs = observations (field notes).

TABLE 3 Characteristics of DHH participants.

Age in years (M, SD; range)	**10.7 (.95); 9.7–12.6**
Gender (*N* females)	2 (25%)
Degree of HL in best ear	
Moderate	3 (37.5.5%)
Moderate-severe	2 (25%)
Severe	3 (37.5%)
Age in years when HL was diagnosed (M, SD; range)	3.1 (3.12); .08–9
Communication mode	
Spoken Dutch	6 (75%)
Dutch sign language	0
Spoken Dutch supported with signs	1 (1.25%)
All (spoke, sign, spoken supported by signs)	1 (1.25%)
Amplification device	
Hearing aids	7 (87.5%)
Cochlear implants	1 (1.25%)
Speech perception	
Excellent	2 (25%)
Good	4 (50%)
Reasonable	2 (25%)
Additional disabilities	1 (1.25%)

Note: Definition of hearing loss (Diefendorf, 2009): Slight 16–25 dB; Mild 26–40 dB; Moderate 41–55 dB; Moderate-severe 56–70 dB; Severe 71–90 dB; Profound 91+ dB.
Abbreviations: DHH, deaf and hard of hearing; HL, hearing loss.

have been shown to correspond to video observations and correlate to self-reported interactions (Elmer et al., 2019; Nasri et al., 2022), indicating its high accuracy and specificity.

Each badge is worn by an individual child in the schoolyard, measuring face-to-face proximity. Every second, when an interaction between two badges is detected, a signal is transmitted to a receiving station located at the schoolyard's border. The receiving station registered signals up to 25 m away, which was adequate for the open schoolyard spaces included in this study. Before the badges were given to the children, it was tested if each of them could be properly detected by the receiving station. To avoid loss of sensitivity due to signal fluctuations an interpolation with a cutoff of 20 s was applied (Cattuto et al., 2010; Elmer et al., 2019; Stehlé et al., 2013). This meant that when two sensors interacted at least twice within a period of 20 s, they were assumed to interact throughout the entire time. This compensation is particularly important for children's interactions, as they may physically move or orient away during a game, or that other objects or children will move between them, while still being involved in a shared social activity. We calculated the percentage of time each student spent in interactions in relation to the total time their badges were identified by the receiving station, rather than the overall recess duration, to allow more accurate comparisons between students.

Number of different partners. The number of partners each student interacted with, based on RFID badges (Cattuto et al., 2010), was calculated as a percentage score, measuring the number of different partners each student interacted with, divided by the total number of participating students minus one. Number of partners complemented the above "time in interactions" measure, by providing data on the quantity and variety of interacting partners, regardless of the duration of these interactions.

Schoolyard observations. Field notes were taken during one assessment per class by two research assistants. The research assistants observed the playground three times per recess, with observations spaced at approximately intervals (2 min at the beginning, middle, and end of recess). They documented the schoolyard behaviors of the DHH students together with their classmates. Data were qualitatively summarized across the two observers for each of the three recess segments. While there were occasional differences in the level of detail provided by observers, no significant differences were found regarding the essential description of students' activities, the positive and/or negative nature of their social interactions or the extent to which the DHH students were observed being alone.

3.2.2 | Peer acceptance

To measure peer acceptance, each student was asked to name their best friends in class. To avoid endless lists that contain weak relationships, the semifixed choice of maximum three was applied (e.g., Pijl et al., 2008). We calculated a standardized score of peer acceptance for each student by summing up the number of nominations they received from peers and then standardizing the score according to the class distribution. This computation captures the extent to which other children consider this child as a social partner, thus indicating the child's social position in the class (Baek et al., 2022; Pijl et al., 2008).

3.2.3 | Friendship

Friendship was defined as a mutual relationship between two peers. Mutuality in relationships requires a reciprocal choice in the nominations task, meaning that two students chose each other as best friends (Pijl et al., 2008). The number of mutual friendships was counted for each student separately and standardized according to the class distribution.

3.2.4 | Sense of peer connectedness

We used the *Relational Provision Loneliness Questionnaire* (RPLQ; Hayden-Thomson, 1989; Dutch version by Goossens & Beyers, 2002) to measure self-reported sense of peer connectedness. The RPLQ includes 14 items, consisting of two 7-items subscales. The first subscale, *Group Integration*, assesses a sense of belonging to the class as a group (e.g., "*I have the feeling that I can get along with my classmates*"). The second subscale, *Peer Intimacy*, assesses the extent to which respondents feel they have a close friend in class they can trust and share personal feelings and thoughts with (e.g., "*I have a friend in my class, to whom I can tell everything*"). Items were slightly adjusted to the school context and to preadolescents' age by using 'classmates' instead of peers, and by using a 3-point scale, ranging from 1 ("*not true*") to 3 ("*true*"). After reverse scoring, a higher mean score indicates a stronger sense of connectedness to classmates. Cronbach alpha reliability of the subscales has been reported as good for both subscales (Goossens & Beyers, 2002). In this study internal consistencies were $\alpha = .84/.80$ for group integration / peer intimacy, respectively.

3.3 | Procedure

The study was approved by the University Ethics Committee. First, we advertised the project in audiological centers, organizations giving services to DHH children and their families, organizations of ambulant teachers for the deaf, and organizations of DHH people or of families of DHH children. Once contact was established with parents of DHH preadolescents attending mainstream educational settings, we informed them about the study's objectives. After receiving their consent, we contacted the class teacher and the school principal to explain the project. Had the school agreed to participate, we presented the project to all classmates and their parents framing it as an assessment of school social participation to prevent stigmatization of DHH participants. Written consent forms were signed by parents of all participating preadolescents, and assent forms were signed by preadolescents aged 12 years or older. Parents of participants who were DHH gave written information on details related to the child's hearing loss. Research assistants gave explanations in the classrooms on the project, including information about the sensors and how they operate, and answered students' questions. Students' privacy was ensured, as well as their right to quit the project at any time. After receiving information about the project participants filled out questionnaires in their classroom. To ensure that all students could fully understand the questionnaires, research assistants read the questionnaire items aloud, explained the Likert-scales and were available to answer any questions from the students.

On the same day, at recess students wore their sensor badges shortly before heading to the schoolyard. With the personal help or supervision of a research assistant, each student attached a sensor badge to their shirt using a safety pin. The safety pins were very small to avoid any damage to the students' shirts. The badges were positioned at the middle of the chest area, to enable quick identification of another badge when two students were in proximity and turn towards each other. As the badges were small and light-weighted, they did not interrupt with student's movements. The students were instructed to play and move naturally without any need to be careful about the badges. According to our impression and similarly to the reports in other studies (e.g., Stehlé et al., 2011; Veiga, Ketelaar, et al., 2017), the badges did not seem to interfere with students' natural activities. Each assessment lasted an average of 22 min (*range* = 12–37 min). At the end of recess, students returned the sensors to the researchers. If needed, they were helped by research assistants to take off the safety pins. The second day of the schoolyard measurements took place approximately two weeks later. During the recess assessments, research assistants stood at the borders of the schoolyard and unobtrusively documented students' activities. Sensor data were recorded by a computerized receiving station located at the border of the schoolyard.

3.4 | Data analyses

The raw sensor data were first preprocessed using Python 3.9 (van Rossum & Drake, 1995). Statistical analyses were performed using SPSS version 27.0 (SPSS Inc., Chicago, IL, USA). For preliminary purposes, we examined the stability of sensor data across assessments per schoolyard, using Intraclass Correlation Coefficient (ICC). For subsequent analyses, we standardized individual sensor and peer nominations data based on the distribution within each student's class. This approach helps to control for potential effects of variations in class sizes (Wolters et al., 2014) and schoolyard sizes on the findings. The associations between sensor data, peer nominations and self-reports were examined via Spearman correlation coefficients because of the non-normal distributions of sensor and self-reports data.

To compare preadolescents with and without hearing loss in social participation measures (schoolyard interactions—interaction time and number of partners, peer acceptance, number of friendships, sense of peer connectedness in terms of group integration and in terms of peer intimacy), we used six independent-samples Mann–Whitney U tests, given that sensor and self-reports data were not normally distributed. For exploratory purposes, as most of the DHH participants were boys (75%), we conducted within the hearing group the same Mann–Whitney tests with sex as a potential confounding variable. Descriptive data were given separately for DHH boys and girls, yet we did not compare between DHH and hearing students within each sex group due to the very small sample size of DHH girls ($N = 2$).

Next, we explored the changes in schoolyard interaction patterns during recess, in terms of interaction time and number of partners, and compared between DHH and hearing participants. Per class, we selected the recess session where we also had observations, which was often the longest session. Except for one school, for which we had only one 12-min-long assessment, all the other seven assessments ranged between 20 and 37 min-long (see Table 2). To compare across all eight assessments, we used 30 min as the cut off. We analyzed the changes over the 30 min using linear mixed models (LMMs) with maximum likelihood estimation (Akaike, 1974) to account for the multilevel structure in our data. We identified three levels in our data: time points (per minute, level 1), nested within participants (level 2), nested within class (level 3). To control for autocorrelation, that is, the dependency between adjacent time points, a First-Order Autoregressive (AR1) covariance structure was applied to level 1 (i.e., time point). We built two models, with interaction time and number of partners as the dependent variable, respectively. For each model, fixed effects included the control variable Sex (0 = boys, 1 = girls); Group (0 = hearing, 1 = DHH); three polynomial terms (Linear, Quadratic, Cubic) for analyzing the changes over time. The interaction effects between Group and the polynomial terms were also added, to examine if the changes over time differed between the two groups. A random intercept for each class was included in both models, to account for the differences between classes. Via a formal model-fitting procedure, we started with the full model with all the effects described above, and then removed nonsignificant factors one by one, starting with the interaction effects. If an effect showed a trend towards significance and removing it reduced the model fit, then it may still stay in the final model. A better model fit was indicated by a lower Akaike information criterion (AIC, Akaike, 1974) and Bayesian information criterion (BIC, Schwarz, 1978). A random intercept for each class was included in both models, to account for the differences between classes. For fixed effects we included the control variable Sex (0 = boys, 1 = girls); Group (0 = hearing, 1 = DHH); as well as three polynomial terms (Linear, Quadratic, Cubic) for modeling the trajectory over time within a recess session. In addition, to further investigate the trend, we divided the recess session into six segments of 5 min each and modeled the interaction time and number of interaction partners with Group, Segment, Group × Segment as fixed effects, and a random intercept for class in LMMs. In this way we examined during which part of the recess session the two groups differed in their social interaction patterns. Finally, given that the number of partners that each child could have may depend on the number of partners that their partners interacted with, we conducted an additional sensitivity analysis to address this possible dependency. In this analysis, we repeated the model for examining the number of partners, but included the average number of partners each child's partner had as a covariate. Adding this covariate, however, did not change the direction of the results (see Appendix 2).

To summarize, the qualitative observations the number of participants was counted per each of the following categories: involvement in activities that include physical objects; interacting in proximity to peers;

TABLE 4 Mean scores of social participation in DHH and hearing students.

	DHH (*M, SD*)	Hearing (*M, SD*)	*N* DHH/Hearing
% Schoolyard time in interactions[a]	–.54 (.88)*,**	.03 (.89)	8 / 173
% Schoolyard N different partners[a]	.26 (.85)	–.001 (.90)	8 / 173
Peer acceptance[a]	–.25 (.88)	.01 (.98)	8 / 184
Mutual friendships[a]	–.30 (1.12)	.01 (1.00)	8 / 184
Sense of connectedness—group integration	2.48 (.24)	2.39 (.47)	8 / 182
Sense of connectedness—peer intimacy	2.30 (.38)*,***	2.57 (.41)	8 / 181

[a]Standardized.
*p (one-tailed) $< .05$.
**$U = 412$, p (one-tailed) $= .026$.
***$U = 422$, p (one-tailed) $= .022$.

negative/neutral/positive valence of interactions; being alone; changes in interaction patterns across time of recess. Specific activities were selected as examples for each observed category. The summary of the observations was descriptively compared to the results of the quantitative time-series analyses and integrated in the discussion.

4 | RESULTS

4.1 | Differences in social participation between DHH and hearing preadolescents

Table 4 presents the mean scores of social participation measures for both groups. Mann–Whitney U tests indicated that preadolescents who were DHH spent less time in schoolyard interactions compared to hearing peers ($N = 181$, $U = 412$, p (one-tailed) $= .026$). There were no group differences in the number of interacting partners. Furthermore, DHH students reported feeling less connected in terms of peer-intimacy compared to hearing peers ($N = 189$, $U = 422$, p (one-tailed) $= .022$), but no significant differences were found in terms of group integration. Finally, DHH students scored lower in peer acceptance and number of friendships, although these differences did not reach statistical significance. Mann–Whitney U tests for the hearing group indicated sex difference, specifically, boys reported lower sense of connectedness in the context of peer intimacy ($N = 181$, $U = 5621.5$, p (two-tailed) $= .000$) and interacted with more partners in the schoolyard compared to girls ($N = 173$, $U = 2965.5$, p (two-tailed) $= .019$) (see Appendix 1).

4.2 | Change across time in patterns of schoolyard interactions

Table 5 presents the final models explaining the overtime changes in interaction time and number of different partners. Regarding interaction time, the fixed effect for Group was observed ($b = –.11$, p(two-tailed) $= .024$) while none of the polynomial terms for the changes over time had an effect. No effects were observed for Sex. This suggests that there were no notable changes in interaction time across time for both groups, with DHH participants spending less time in interactions throughout recess (see Figure 1a). The 5-min segment analysis confirmed this finding, where DHH students presented shorter interaction time across all time segments.

Regarding number of partners, significant fixed effects were observed for Sex ($b = –.04$, p(two-tailed) $< .001$), Linear term ($b = .16$, p(two-tailed) $< .001$), and for Cubic term ($b = –.04$, p(two-tailed) $= .016$), while no other fixed effects were noted. Findings suggested that girls tend to interact with fewer partners than boys. Also, for both DHH and hearing students, they interacted with a relatively low number of partners at the beginning of the recess, and then showed an increase and a subsequent decrease towards the end of recess (see Figure 1b). No differences were found in the number of partners across time between the groups. However, the additional analysis with 5-min segments indicated

TABLE 5 Regression weights (standard error) examining group differences and changes across recess time in schoolyard interaction time and number of partners.

	Playground interaction time Estimate (SE)	Playground N partners Estimate (SE)
Over-time trajectory[a]		
Intercept	.64 (.04)***	.18 (.03)***
Sex	.01 (.02)	–.04 (.01)***
Group	–.11 (.05)*	–.02 (.02)
Linear	–	.16 (.03)***
Quadratic	–	–
Cubic	–	–.04 (.02)*
Intercept variance (subject = class)	.01 (.004)	.005 (.002)
Residual variance (repeated measures = time)	.11 (.004)***	.02 (.001)***
Five-min segment		
Intercept	.66 (.04)***	.15 (.03)***
Sex	.01 (.02)	–.04 (.01)***
Group	–.11 (.05)*	.02 (.03)
Segment	–.01 (.01)	.01 (.003)***
Group × Segment	–	–.02 (.01)*
Intercept variance (subject = class)	.01 (.005)	.005 (.003)
Residual variance (repeated measures = time)	.11 (.004)***	.02 (.001)***

Note: Classes 4 and 5 were clustered together as they attended the schoolyard at the same assessment.
[a]Interaction effects are removed from the final model, hence not shown here.
*p *(two-tailed)* < .05; ** $p < .01$; *** $p < .001$.

an interaction of Group × Segment ($b = –.02$, p(two-tailed) = .042). This indicated that the DHH and hearing students showed different patterns in the number of partners they interacted with over time. Follow-up tests showed that it was during the last 5 min of recess that DHH students interacted with fewer peers than the hearing students, with a marginally significant effect (t(3177) = 1.95, adjusted p(two-tailed) = .051). As (b) shows, it seems that after the first 15 min of recess DHH participants began interacting with fewer partners, and this difference became more noticeable at the end of the recess. Therefore, not only did DHH participants spend less time in interactions throughout recess, but they also became increasingly isolated the longer the recess lasted, while this temporal pattern was not observed for their peers.

A sensitivity analysis, controlling for the average number of partners each student's partner had, was conducted to evaluate the robustness of the model. The direction of the results did not change. Furthermore, in the analysis with 5-min segments, it was confirmed that DHH students interacted with fewer peers in the last 5 min compared to hearing counterparts (t(3164) = 2.02, adjusted $p = .043$). Detailed findings from this analysis are provided in Appendix 2.

4.3 | Stability of sensor data and correlations between social measures

Sensor data ICCs (see Table 6) indicates moderate stability over the available assessments per schoolyard for both the interaction time and the number of different partners. Spearman correlations indicate positive associations

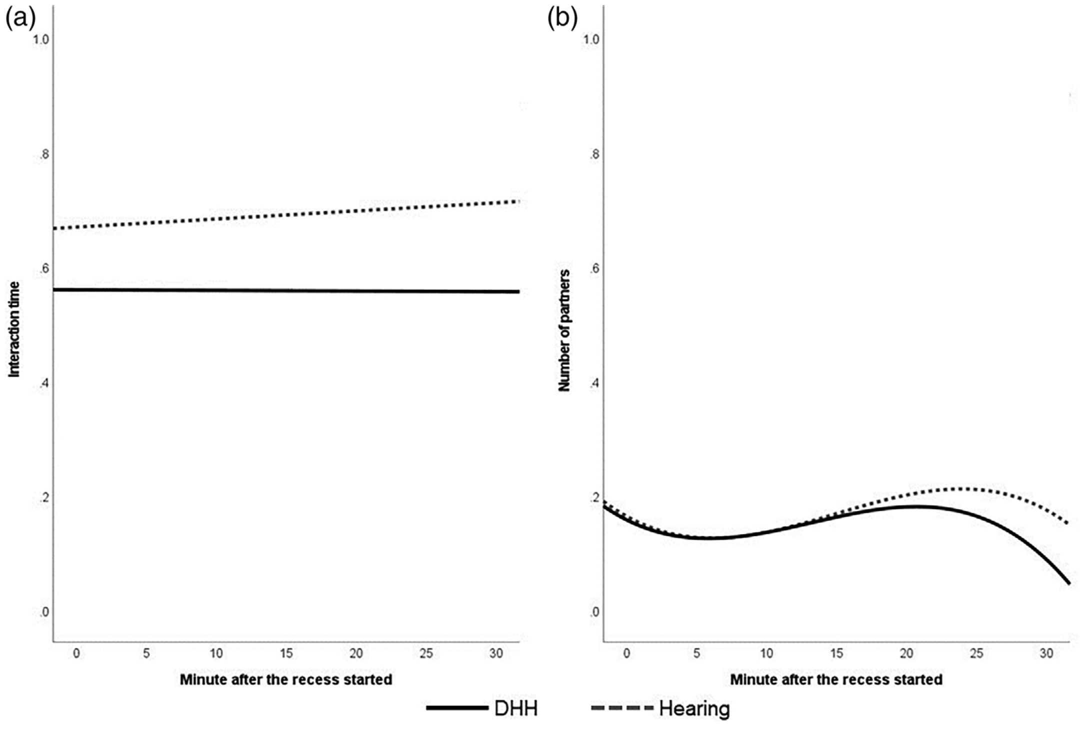

FIGURE 1 Changes across time in patterns of schoolyard interaction time and number of partners in DHH and hearing students.

TABLE 6 Stability of sensor data across assessments.

	Over 2 assessments	Over 3 assessments
% Time in interactions	.681***	.640***
% *N* different partners	.554***	.603***

Note: ICC, intraclass correlation coefficient, applied for average measures in a two-way mixed effects model. $N = 117/57$ for two/three assessments, respectively.
***p (two-tailed) < .000.

between time spent in schoolyard interactions, as measured by sensors, and nomination-based peer acceptance ($r(201) = .173$, p (two-tailed) = .014), as well as mutual friendships ($r(200) = .160$, p (two-tailed) = .024) (see Table 7). In addition, significant positive associations were found between the time the students spent in schoolyard interactions and their self-reported sense of connectedness in the context of group integration ($r(180) = .146$, p (two-tailed) = .050). Significant correlations were also found between self-reported sense of group integration and nomination-based peer acceptance ($r(190) = .252$, p (two-tailed) = .000), as well as mutual friendships ($r(189) = .224$, p (two-tailed) = .002).

4.4 | Qualitative observations

Table 8 presents a summary of the filed notes taken for each DHH participant, at three distinct assessment times. In six out of eight assessments, the DHH students were observed throughout recess in activities that involve physical

TABLE 7 Spearman correlations between sensor data, peer nominations and self-reports.

	1	2	3	4	5
1. % Schoolyard time in interactions[a]					
2.% Schoolyard *N* different partners[a]	.559***				
3. Peer acceptance[a]	.173*	.085			
4. Mutual friendships[a]	.160*	.076	.730***		
5. Sense of connectedness—group integration	.146*	.043	.252***	.224**	
6. Sense of connectedness—peer intimacy	−.008	−.066	.117	.084	.394***

[a]Standardized according to the class' mean score and standard deviation. $N = 179–201$.
*p *(two-tailed)* $< .05$; ** $p < .01$; *** $p < .001$.

objects (reading a book, playing ping-pong, or most commonly—football). Proximity to peers was described as both positive (e.g., talking and smiling, involved in the game, playing catch and run; $N = 4$) and negative interactions (e.g., trying to join in but being ignored, peers taking a desired object from the DHH student, standing in the group but not seeming to understand what is going on, fighting; $N = 5$). Notably, five out of eight DHH students were not interacting with peers for all or most of their recess time (e.g., reading a book alone, walking around and watching others, being part of a football team but actually standing alone at the borders of the football area). Exploring patterns of schoolyard behavior across time, three students did not show any change in patterns, because they were observed alone consistently or because of a short recess duration. The other five students showed variability across recess, with only two showing increase in interactions from the beginning to the middle parts of recess, and most of them ($N = 4$) showing decrease in interactions from the middle part onwards (e.g., standing afar, taking many breaks, playing alone or sitting alone and staring).

5 | DISCUSSION

This explorative study uniquely used wearable proximity sensors to continuously detect social interactions of preadolescents who are DHH in mainstream schoolyards, compared to hearing peers. This study combined measurement of schoolyard interactions together with more traditional measures of social inclusion, including peer acceptance, friendships, and students' own perception of their social situation. Among these measures, schoolyard interactions, based on sensor data in combination with field notes, were found to differ between the groups, suggesting that compared to hearing peers DHH students spent less time in interactions throughout recess and became more isolated the longer the recess lasted. Further, even those DHH students who were in proximity to peers did not always show positive interactions or social involvement, as some observations suggested.

Sensor data for all students showed in our study moderate stability across assessments, therefore adequate for drawing generalized conclusions on schoolyard behaviors. Positive correlations were found for all preadolescents between the time spent at schoolyard interactions, based on sensors, the degree to which they were accepted by classmates and the number of friendships they had, based on unidirectional or mutual peer nominations, respectively, and self-reported sense of connectedness in the context of group integration. However, it should be noted that these correlations were small-sized, and that no relations were found between schoolyard interactions and sense connectedness in the context of peer intimacy. Possibly, schoolyard dynamics bear their own characteristics and some preadolescents flourish in the schoolyard environment while others express themselves better in other contexts. Further, schoolyard behaviors may serve as indicators of group dynamics rather than solely reflecting one-on-one relationships. This suggestion is further strengthened by the finding that within the hearing group boys tended to

TABLE 8 Schoolyard observations on social participation of DHH children.

Class (recess duration)	Recess segment	Schoolyard behaviors
1 (23 min)	1st	Reading a book alone.
	2nd	Reading a book alone.
	3rd	Reading alone + walking around, kids come close to him but ignore him.
2 (29 min)	1st	Goal keeper at the football game.
	2nd	Goal keeper. Stares, asks where the ball is (seems to be outside of what is happening).
	3rd	Goal keeper. Started playing with the ball but then someone took the ball from him & he seemed frustrated.
3 (25 min)	1st	Playing ball game with kids.
	2nd	Playing ball with kids, but sometimes stands further and looks a bit afar.
	3rd	Takes a break. Withdrawn. Watches others playing a ball, few times tries to participate but stays aside.
4 (12 min)	1st	Plays at the ping pong table. Stands at the outskirts of the table, but also walks around and talks to other children.
	2nd	Finds a new position to join the ping pong table, smiles, talks to other children, walks around.
	3rd	Plays ping pong, smiles.
6 (27 min)	1st	Alone, walks around, watches others. Tries to join others but not accepted.
	2nd	Watches others + plays catch & run with kids.
	3rd	Tries to participate but does not succeed. Watches others. After a while just sits alone and watches others.
8 (20 min)	1st	Rolling on the bar and talking to a student next to her, then plays catch & run with that student.
	2nd	Running around alone, talking to herself, detached from surrounding, pretends to fly, climbs the glide.
	3rd	A student is talking to her but she is sitting and doesn't seem to respond much.
9 (21 min)	1st	Playing football with a group, but standing at the borders of the play area, without speaking or getting to touch the ball.
	2nd	Playing football, dancing to herself, chatting with kids and fighting with another kid.
	3rd	Still playing football but is also spending much time alone.
10 (36 min)	1st	Playing football in a group. Often stands alone, tying his laces or seems to be at the outskirts. Sometimes making remarks but they are not directed to specific kids and students do not respond to them.
	2nd	Same as above
	3rd	Same as above

interact with a larger number of partners compared to girls (see Appendix 1). It is possible that boys may define friendships in terms of participation in shared activities rather than relying solely on intimate communication. Previous research has demonstrated that boys engage in larger groups while girls in smaller and more intimate interactions (Maccoby, 1990). These findings align with the sex differences observed in both our sensor data and self-reports.

When compared with hearing classmates, DHH preadolescents spent less time interacting in the schoolyard, both across recesses and throughout each minute of recess. Considering that schoolyard dynamics may involve to a large extent group interactions, these findings demonstrate in natural settings previous experimental tasks (Martin et al., 2010), that is, that it is harder for DHH students to participate in groups compared to one-on-one settings. DHH students in our study also reported feeling less connected in the context of intimate friendships. Fewer friendships or less positive features in friendships were also reported in previous studies with DHH preadolescents and early adolescents (Nunes et al., 2001; Rieffe et al., 2018). However, since most of the DHH students were boys and exploratory analyses showed that hearing boys reported lower sense of peer intimacy compared to girls, sex could not be ruled out as a confounding variable. An interaction between sex and hearing loss may also explain our findings, as there is some evidence that DHH boys and girls in mainstream education may differ in the extent of their social inclusion and in the factors that contribute to it. In a study with early-adolescents Wolters and colleagues (2011) found that DHH boys were less accepted compared to DHH girls, that peer acceptance was predicted by prosocial behavior, and that DHH girls showed higher rates of prosocial behavior compared to DHH boys. At the same time, peer acceptance was predicted by different communicative skills for DHH boys and girls (Wolters et al., 2011). Sex differences in effectiveness of strategies for social participation were also noted in a study based on interviews with parents of DHH students (Martin & Bat Chava, 2003). Given that boys tend to interact in larger and less intimate groups (Maccoby, 1990), it is possible that our mostly male sample was particularly sensitive to social isolation in the context of schoolyard group dynamics. Yet, it should be noted at the descriptive level that both DHH boys and girls had lower scores in sense of peer intimacy and in time spent in schoolyard interactions compared to peers of the same sex (see Appendix 1).

Contrary to our expectations, students who were DHH did not report on lower sense of connectedness in the context of group integration. In addition, no significant differences were found between the groups in peer acceptance and number of friendships, although some nonsignificant tendencies for lower social participation were noted. There are different possible interpretations for the gap found between schoolyard interactions and other aspects of social inclusion. From a methodological viewpoint, it is possible that some differences in social participation, for example, lower peer acceptance and smaller number of friendships, did not reach statistical significance because of the small sample-size of the DHH group. Possibly, multiple interactions measured repeatedly and continuously over a certain time-period capture social dynamics more sensitively compared to peer nominations and self-reports taken at a single timepoint.

From a conceptual viewpoint it could be argued that schoolyard interactions measure something different than peer acceptance or friendships. For example, interventions that succeed at increasing interactions between students with and without disabilities do not necessarily create a change in peer acceptance or friendships, because these interactions may lack the quality of intimacy or reciprocity (Reviews by Raedemaker et al., 2020; Tsou et al., 2024). It is possible that students who are DHH are more isolated during recess because of the acoustic characteristics of the schoolyard dynamics, yet they succeed in forming good relationships with at least one classmate. Having friendships may also explain the lack of differences in sense of group integration despite DHH participants' fewer interactions during recess, as the existence of friends may protect against difficulties in other aspects of social inclusion such as peer rejection (Bukowski et al., 2009; Garrote et al., 2017). Alternatively, researchers of social inclusion have suggested that students with disabilities, especially young children, display a positive self-perception bias, because of social desirability or lack of social awareness (e.g., Pijl et al., 2008; Koster et al., 2010). It is possible that some DHH preadolescents still have low awareness or low expectations of participation in group dynamics, resulting in a relatively positive sense of group integration. This may change during adolescence with a growing cognitive, emotional and social awareness, as can be learnt from reports of DHH adolescents and young adults (Eichengreen et al., 2021; Punch & Hyde, 2011). In addition to possible self-bias, self-reports are argued to provide unique but narrowed information (Fryer & Dinsmore, 2020). For example, they provide limited access to information about the fluctuating and dynamic nature of interactions as they evolve over time and affect each other within varied contexts (Rogat et al., 2022). It has also been shown that self-reports alone cannot fully capture dynamic group processes, for eaxmple, how group dynamics predict individuals' affective states (Vriesema & McCaslin, 2020). The combination of sensor data with self-reports in this study therefore fits previous research recommendations for synergistic use of multiple methods (Fryer & Dinsmore, 2020).

The findings of this study suggest that sensor data pointed at social difficulties not detected by other, more traditional measures. Sensor data findings were in line with our field observations, according to which most of the DHH students were alone most or all of their recess time. Our findings therefore highlight the importance of considering the schoolyard context when evaluating students' social inclusion. Considering that self-reports may be biased or provide limited information, and that teachers may overlook students who are socially neglected (Gifford-Smith & Brownell, 2003; Pijl et al., 2008), it is therefore important that researchers use such multimethod designs to achieve a fuller understanding of students' social participation.

This study uniquely applied a continuous approach to studying social interactions, with a special focus on trajectory of interaction patterns across time. While the number of partners was similar across recess for DHH and hearing students, posthoc analysis indicated group changes across time. Specifically, as recess proceeded, while hearing participants interacted with increasingly more partners, DHH participants showed a decrease in their number of partners with time, with a sharper decline towards the end of recess. This was also noted in the observations, where half of the DHH students were observed keeping a physical distance from their peers towards the end of recess. Perhaps the efforts DHH students needed to invest in following communication in such a noisy environment made them increasingly tired (Bess et al., 2020), or that they withdrew because of accumulated failures to interact. The potential cumulative effects of recess on DHH students' social isolation therefore deserve further research. Further, previous research pointed at interpersonal synchronization between children's movements as an indicator for their interpersonal closeness (Review by Horn et al., 2024). A time-series analysis of social patterns during recess, albeit based on proximity as conducted in this study, demonstrates the utility of proximity sensors in detecting lack of temporal synchronization, such as instances where certain students become increasingly isolated compared to their classmates, in natural settings. This approach holds particular value for research on social inclusion, as the temporal dimension remains underexplored in this field. Recent observation studies pointed at the advantages of researching the temporal dimension of group dynamics, elucidating how socio-emotional interactions develop or escalate over time and influence subsequent group cooperation and engagement (Jones et al., 2022; Rogat et al., 2022). Our time-series investigation illustrates how temporal data can enhance understanding of the evolving dynamics of social exclusion. Unlike observation methods, sensor-based methodologies offer distinct advantages for studying schoolyard dynamics, enabling cost-effective objective collection of large-datasets capturing continuous and simultaneous dynamics within large groups.

Finally, our observations suggested that proximity to peers was not always indicative of positive interactions. For example, when a DHH student was present within a group but not actively engaged in communication, or when peers did not respond to the student. A previous study has also highlighted that physical proximity, especially in large groups, does not necessarily reflect the quality of interaction (Eichengreen, van Rooijen et al., 2023). As noted by Raedemaker and colleagues (2020), while peer interactions may provide the building blocks for forming positive relationships, they alone are not sufficient. Further research is warranted on the nuanced and dynamic qualities of these interactions to understand why they succeed or fail in fostering motivation to interact or sense of mutual connectedness. Even when positive communication exchanges occur, they may be superficial and short-lived, or peers may respond out of willingness to help rather than a genuine sense of mutuality, as was noted in previous interviews with friends of DHH students (Nunes et al., 2001). Hence, it is important in future research to integrate proximity-based sensor data with more sophisticated detection methods for interactions' valence and dynamics to achieve a full comprehensive understanding of the extent and underlying reasons for students' social isolation.

5.1 | Practical implications

Our findings suggest that schoolyard dynamics indicate group interactions rather than close friendships, and that not all preadolescents fulfill their social potential during recess. The implications for practice derived from the study suggest that there is a need for intentional modifications and adaptations of the school environment during recess to better address the social needs of all students. This may include the incorporation of accessibility features such as shielded areas or more greenery to improve acoustics and provide protected spaces for quiet activities or recovery from sensory overarousal (Tsou et al., 2024). Additionally, environments that afford a diverse range of individual, dyadic and group activities to choose from during recess may contribute to a more inclusive and engaging recess. These could include opportunities for collaborative games such as building towers or obstacle courses, and creative play (McNamara, 2017). Furthermore, adults and older peers who can serve as role models and social coordinators can foster positive social interactions, provide guidance for neglects and conflicts, and facilitate a supportive atmosphere during recess (McNamara, 2017; Eichengreen, van Rooijen et al., 2023). In essence, the practical implications underscore the importance of intentionally designing recess environments by creating physically accessible and socially supportive spaces. Future research should investigate modification and adaptions to formulate evidence-based guidelines for recess and schoolyards in particular. Furthermore, the findings of this study highlight the potential of wearable proximity sensors for investigating the schoolyard dimension of social inclusion, given their ability to track students' behaviors continuously and overtime in their natural environment. With a combination of different sensors, previous studies had shown that such technologies can be used to assess how changes in the schoolyard design affect children's spatial behavior and social interactions (Nasri et al., 2022; Moreira et al., 2022). This could be further studied in relation to interventions that increase physical and acoustic accessibility of the schoolyard, as well as creating a socially supportive recess environment.

5.2 | Limitations and suggestions for future research

This exploratory study was the first attempt to capture different dimensions of social participation among DHH students in seven mainstream schools using a multimethod approach, offering valuable insights into the social inclusion of mainstreamed DHH preadolescents. Yet, due to the individual integration of DHH students within the mainstream setting, our findings are based on an unbalanced design with a small sample size of DHH preadolescents, which may not be generalizable to the broader population of DHH preadolescents. Also, as a field study conducted across diverse regions of the country, with a limited number of schools, data could not be attained in identical conditions for all classes (e.g., the timing and duration of recess and the number of assessments conducted). While our findings underscore the need for further understanding of social patterns and challenges faced by DHH students, future studies are encouraged to replicate current findings under more controlled conditions and with stratified sampling from a larger and more representative sample of DHH students.

In addition, most of our DHH participants were males, with moderate to moderate-severe hearing loss and no additional disabilities, using hearing aids and communicating through spoken language. Previous research has pointed out additional disabilities and limited spoken communication abilities as risk factors for social inclusion in mainstream settings (review by Batten et al., 2014; Olsson et al., 2018). The findings of this study might therefore not fully reflect the intensity and breadth of social difficulties experienced by DHH students and may explain why our sample did not significantly differ from hearing peers in some of the social dimensions assessed. Further, it is unclear to what extent our findings can be generalized to cochlear-implant users, as research has shown that early cochlear implantation is associated with less feelings of loneliness in mainstream settings (Schorr, 2006), but also that cochlear-implant users still experience more social difficulties compared to hearing peers (Punch & Hyde, 2011). With regards to the potential interaction of hearing loss and sex in our sample, it is possible that DHH boys may engage in large group activities or sports, yet experience limited social inclusion by peers during these activities. Hence, future research should aim to widen the representation of the DHH population in mainstream schools by including more females, students with severe to profound hearing loss, cochlear implants users, and sigh language users. Additionally, larger sample sizes would facilitate the examination of possible interactions between hearing loss, sex, and additional disabilities.

In this study, proximity sensor data were moderately stable and were related to some measures of social participation. Furthermore, sensor data proved to be sensitive to detecting differences between DHH and hearing preadolescents, as well as to sex differences. It is possible, however, that fluctuations in sensor sensitivity may have resulted in some interactions not being captured. For instance, in a study involving adults (Elmer et al., 2019), RFID sensors exhibited approximately 50% sensitivity, correctly identifying half of all interactions, with high specificity (97%) and accuracy (87%). While we followed prior research suggestions to improve sensitivity with interpolation (Elmer et al., 2019), it is plausible that our sensors failed to capture brief interactions particularly when preadolescents were orienting side-by-side, engaging in dynamic activities, or participating in games where they maintained distances exceeding 1.5 m for more than 20 s (e.g., football, catch and run). Therefore, future research could benefit from integrating proximity sensors with additional sensing technologies, such as location-based GPS loggers (Nasri et al., 2022) to provide more comprehensive datasets and improve sensitivity to social interactions.

Another limitation of this study pertains to the potential dependency within the data that may not be addressed fully by the linear mixed models. Given that our study took place in schoolyards where the participants interacted with each other, their social behaviors could be dependent on the social behaviors of one another. While we attempted to address this issue by controlling for the average number of partners each child's partner had in an additional analysis, aiming to mitigate the potential effects of this dependency, further research should explore additional methods to address the dynamic nature of schoolyard interactions.

As wearable sensors represent a novel technology, ethical concerns arise regarding their inclusion in research, especially when involving minors. In line with recommendations for future standardization of ethical guidelines in this field (Horn et al, 2024), we implemented several steps to protect the anonymity and privacy of the participants. These measures included informing them about the nature of the data collected by the sensors as well as their ethical rights, and obtaining legal consent from both the participants and their legal guardians.

Another consideration pertains to the interpretation of the sensor data. As demonstrated in this study, proximity sensors may potentially underestimate social isolation, as interactions in proximity may bear neutral or even negative valence. Future research could therefore benefit from integrating sensing technology with innovative approaches for assessing interaction quality, not yet applied to the schoolyard context. These include microinteraction-based ecological momentary assessment (μEMA; Ponnada et al., 2022) or machine-learning emotion detection (Quiroz et al., 2022). Furthermore, the utilization of machine learning algorithms to identify and classify patterns in the data (Horn et al., 2024), the attachment of speech-recorders to the sensors (Altman et al., 2020), or a combination of both, offer new avenues for detecting interaction quality in various group settings. Such advancements are particularly relevant for research on social inclusion, especially concerning students facing communication-challenges.

6 | CONCLUSION

The findings of this explorative study suggest that DHH preadolescents who are individually integrated in mainstream classes spend less time interacting with peers in the schoolyard during recess. Posthoc findings and qualitative observations suggest that they may become increasingly isolated the longer the recess lasts. Findings exemplify how a multimethod design that targets several dimensions of social participation, based on both single time-point and time-series analyses, contributes to a rich understanding of students' social lives at school. In particular, findings highlight the importance of researching schoolyard interactions when evaluating social inclusion, and that wearable proximity sensors in combination with field notes are highly valuable for detecting continuous multiple schoolyard social dynamics.

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CONFLICT OF INTEREST STATEMENT

The authors report no conflicts of interest. The authors declare no financial interests.

ETHICS STATEMENT

All procedures performed in this study were in accordance with the ethical standards of Leiden University Ethics Committee (approval number CEP19-0402/253) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

DATA AVAILABILITY STATEMENT

The dataset and associated information used in the current study will be archived on the Leiden University archiving platform DataverseNL (https://dataverse.nl/) once the manuscript is accepted, with the DOI number: https://doi.org/10.34894/BAF871.

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ENDNOTE

[1] Hearing loss/deafness can be a claimed identity for some students, a medical condition undefining self-identity for others, and for others somewhere in between. We respect all approaches and preferences based on individuals' personal choice.

REFERENCES

Akaike, H. (1974). A new look at statistical-model identification. *IEEE Transactions on Automatic Control*, *19*, 716–723. https://doi.org/10.1109/TAC.1974.1100705

Altman, R. L., Laursen, B., Messinger, D. S., & Perry, L. K. (2020). Validation of continuous measures of peer social interaction with self- and teacher-reports of friendship and social engagement. *European Journal of Developmental Psychology*, *17*(5), 773–785. https://doi.org/10.1080/17405629.2020.1716724

Baek, E. C., Hyon, R., López, K., Finn, E. S., Porter, M. A., & Parkinson, C. (2022). In-degree centrality in a social network is linked to coordinated neural activity. *Nature Communication*, *13*(1), 1118. https://doi.org/10.1038/s41467-022-28432-3

Batten, G., Oakes, P. M., & Alexander, T. (2014). Factors associated with social interactions between deaf children and their hearing peers: A systematic literature review. *The Journal of Deaf Studies and Deaf Education*, *19*(3), 285–302. https://doi.org/10.1093/deafed/ent052

Bess, F. H., Davis, H., Camarata, S., & Hornsby, B. W. Y. (2020). Listening-related fatigue in children with unilateral hearing loss. *Language, Speech, and Hearing Services in Schools*, *51*(1), 84–97. https://doi.org/10.1044/2019_LSHSS-OCHL-19-0017

Brunnberg, E. (2005). The school playground as a meeting place for hard of hearing children. *Scandinavian Journal of Disability Research*, *7*(2), 73–90. https://doi.org/10.1080/15017410510032163

Bukowski, W. M., Motzoi, C., & Meyer, F. (2009). Friendship as process, function, and outcome. In K. H. Rubin, W.M. Bukowski, & B. Laursen (Eds.), *Handbook of peer interactions, relationships, and groups* (pp. 217–231). The Guilford Press.

Cattuto, C., van den Broeck, W., Barrat, A., Colizza, V., Pinton, J. F., & Vespignani, A. (2010). Dynamics of person-to-person interactions from distributed RFID sensor networks. *PLoS ONE*, *5*(7), e11596–e11596. https://doi.org/10.1371/journal.pone.0011596

Crone, E., & Dahl, R. (2012). Understanding adolescence as a period of social–affective engagement and goal flexibility. *Nature Reviews Neuroscience*, *13*, 636–650. https://doi.org/10.1038/nrn3313

Dalton, C. J. (2013). Lessons for inclusion: Classroom experiences of students with mild and moderate hearing loss. *Canadian Journal of Education*, *36*(1), 125–152. https://www.jstor.org/stable/canajeducrevucan.36.1.125

Diefendorf, A. O. (2009). Assessment of hearing loss in children. In Katz J., Medwetsky L., Burkard R., & Hood L. (Eds.), *Handbook of clinical audiology* (6th ed., pp 545–563). Wolters Kluwer/Lippincott Williams & Wilkins.

Edmondson, S., & Howe, J. (2019). Exploring the social inclusion of deaf young people in mainstream schools, using their lived experience. *Educational Psychology in Practice*, *35*(2), 216–228. https://doi.org/10.1080/02667363.2018.1557113

Eichengreen, A., Hoofien, D., & Bachar, E. (2016). Empirically-based suggested insights into the concept of False-Self defense: Contributions from a study on normalization of children with disabilities. *Journal of the American Psychoanalytic Association*, *64*, 107–132. https://doi.org/10.1177/0003065115616843

Eichengreen, A., Zaidman-Zait, A., Most, T., & Golik, G. (2021). Resilience from childhood to young adulthood: Retrospective perspectives of deaf and hard of hearing people who studied in regular schools. *Psychology & Health*, *37*(3), 331–349. https://doi.org/10.1080/08870446.2021.1905161

Eichengreen, A., Tsou, Y.-T., Nasri, M., van Klaveren, L. M., Li, B., Koutamanis, A., Baratchi, M., Blijd-Hoogewys, E., Kok, J., & Rieffe, C. (2023). Social connectedness at the playground before and after COVID-19 school closure. *Journal of Applied Developmental Psychology*, *87*, 101562. https://doi.org/10.1016/j.appdev.2023.101562

Eichengreen, A., van Rooijen, M., van Klaveren, L. M., Nasri, M., Ysou, Y.-T., Koutamanis, A., Baratchi, M., & Rieffe, C. (2023). The impact of loose-parts-play on schoolyard social participation of children with and without disabilities: A case study. *Child: Care, Health and Development*, *50*, 1–15. https://doi.org/10.1111/cch.13144

Elmer, T., Chaitanya, K., Purwar, P., & Stadtfeld, C. (2019). The validity of RFID badges measuring face-to-face interactions. *Behavior Research Methods*, *51*(5), 2120–2138. https://doi.org/10.3758/s13428-018-1180-y

Fryer, L. K., & Dinsmore, D. L. (2020). The promise and pitfalls of self-report: Development, research design and analysis issues, and multiple methods. *Frontline Learning Research*, *8*(3), 1–9. https://doi.org/10.14786/flr.v8i3.623

Garrote, A., Dessemontet, R. S., & Opitz, E. M. (2017). Facilitating the social participation of pupils with special educational needs in mainstream schools: A review of school-based interventions. *Educational Research Review*, *20*, 12–23. https://doi.org/10.1016/j.edurev.2016.11.001

Gifford-Smith, M. E., & Brownell, C. A. (2003). Childhood peer relationships: Social acceptance, friendships, and peer networks. *Journal of School Psychology*, *41*(4), 235–284. https://doi.org/10.1016/S0022-4405(03)00048-7

Goossens, L., & Beyers, W. (2002). Comparing measures of childhood loneliness: Internal consistency and confirmatory factor analysis. *Journal of Clinical Child and Adolescent Psychology*, *31*(2), 252–262. https://doi.org/10.1207/S15374424JCCP3102_10

Hayden-Thomson, L. K. (1989). The development of the Relational Provisions Loneliness Questionnaire for children. *Unpublished doctoral dissertation, University of Waterloo, Waterloo, Ontario, Canada*.

Heravi, B. M., Gibson, J. L., Hailes, S., & Skuse, D. (2018). Playground social interaction analysis using bespoke wearable sensors for tracking and motion capture. *Proceedings of the 5th International Conference on Movement and Computing*, 1–8. https://doi.org/10.1145/3212721.3212818

Horn, L., Karsai, M., & Markova, G. (2024). An automated, data-driven approach to children's social dynamics in space and time. *Child Development Perspectives*, *18*(1), 36–43. https://doi.org/10.1111/cdep.12495

Jarvis, P., Newman, S., & Swiniarski, L. (2014). On 'becoming social': The importance of collaborative free play in childhood. *International Journal of Play*, *3*(1), 53–68. https://doi.org/10.1080/21594937.2013.863440

Jones, C., Volet, S., Pasternak, D. P., & Heinimäki, O. P. (2022). Interpersonal affect in groupwork: A comparative case study of two small groups with contrasting group dynamics outcomes. *Frontline Learning Research*, *10*(1), 46–75. https://doi.org/10.14786/flr.v10i1.851

Koster, M., Nakken, H., Pijl, S. J., & Houten, E. (2009). Being part of the peer group: A literature study focusing on the social dimension of inclusion in education. *International Journal of Inclusive Education*, *13*(2), 117–140. https://doi.org/10.1080/13603110701284680

Koster, M., Pijl, S. J., Nakken, H., & Van Houten, E. (2010). Social participation of students with special needs in regular primary education in the Netherlands. *International Journal of Disability, Development and Education*, *57*(1), 59–75. https://doi.org/10.1080/10349120903537905

Krijger, S., Coene, M., Govaerts, P. J., & Dhooge, I. (2020). Listening difficulties of children with cochlear implants in mainstream secondary education. *Ear and Hearing*, *41*(5), 1172–1186. https://doi.org/10.1097/AUD.0000000000000835

Maccoby, E. E. (1990). Gender and relationships: A developmental account. *American Psychologist*, *45*, 513–520. https://doi.org/10.1037/0003-066X.45.4.513

Martin, D., & Bat-Chava, Y. (2003). Negotiating deaf–hearing friendships: Coping strategies of deaf boys and girls in mainstream schools. *Child: Care, Health and Development*, *29*(6), 511–521. https://doi.org/10.1046/j.1365-2214.2003.00371.x

Martin, D., Bat-Chava, Y., Lalwani, A., & Waltzman, S. B. (2010). Peer relationships of deaf children with cochlear implants: Predictors of peer entry and peer interaction success. *Journal of Deaf Studies and Deaf Education*, *16*(1), 108–120. https://doi.org/10.1093/deafed/enq037

McNamara, L., Colley, P., & Franklin, N. (2017). School recess, social connectedness and health: A Canadian perspective. *Health Promotion International*, *32*(2), 392–402. https://doi.org/10.1093/heapro/dav102

Moreira, M., Cordovil, R., Lopes, F., Da Silva, B. M. S., & Veiga, G. (2022). The Relationship between the quality of kindergartens' outdoor physical environment and preschoolers' social functioning. *Educational Sciences*, *12*, 661. https://doi.org/10.3390/educsci12100661

Morrow, M. T., Hubbard, J. A., & Sharp, M. K. (2019). Preadolescents' daily peer victimization and perceived social competence: Moderating effects of classroom aggression. *Journal of Clinical Child & Adolescent Psychology*, *48*(5), 716–727. https://doi.org/10.1080/15374416.2017.1416618

Most, T. (2007). Speech intelligibility, loneliness, and sense of coherence among deaf and hard-of-hearing children in individual inclusion and group inclusion. *Journal of Deaf Studies and Deaf Education*, *12*(4), 495–503. https://doi.org/10.1093/deafed/enm015

Murray, R., & Ramstetter, C. (2013). The crucial role of recess in school. *Pediatrics*, *131*(1), 183–188. https://doi.org/10.1542/peds.2012-2993

Nasri, M., Tsou, Y.-T., Koutamanis, A., Baratchi, M., Giest, S., Reidsma, D., & Rieffe, C. (2022). A novel data-driven approach to examine children's movements and social behavior in schoolyard environments. *Children*, *9*(8), 1177. https://doi.org/10.3390/children9081177

Nunes, T., Pretzlik, U., & Olsson, J. (2001). Deaf children's social relationships in mainstream schools. *Deafness & Education International*, *3*(3), 123–136. https://doi.org/10.1179/146431501790560972

Oliva, G. (2007). Looking back… Longing for a group of friends. *Odyssey: New Directions in Deaf Education*, *8*, 14–18.

Olsson, S., Dag, M., & Kullberg, C. (2018). Deaf and hard-of-hearing adolescents' experiences of inclusion and exclusion in mainstream and special schools in Sweden. *European Journal of Special Needs Education*, *33*(4), 495–509. https://doi.org/10.1080/08856257.2017.1361656

Paatsch, L., & Toe, D. (2020). The impact of pragmatic delays for deaf and hard of hearing students in mainstream classrooms. *Pediatrics*, *146*(Supplement_3), S292–S297. https://doi.org/10.1542/peds.2020-0242I

Pijl, S J., Frostad, P., & Flem, A. (2008). The social position of pupils with special needs in regular schools. *Scandinavian Journal of Educational Research*, *52*(4), 387–405. https://doi.org/10.1080/00313830802184558

Ponnada, A., Wang, S., Chu, D., Do, B., Dunton, G. F., & Intille, S. S. (2022). Intensive longitudinal data collection using microinteraction ecological momentary assessment: Pilot and preliminary results. *JMIR Form Res*, *6*(2), e32772. https://doi.org/10.2196/32772

Punch, R., & Hyde, M. (2011). Social participation of children and adolescents with cochlear implants: A qualitative analysis of parent, teacher, and child interviews, *Journal of Deaf Studies and Deaf Education*, *16*(4), 474–493. https://doi.org/10.1093/deafed/enr001

Quiroz, M., Patiño, R., Diaz–Amado, J., & Cardinale, Y. (2022). Group emotion detection based on social robot perception. *Sensors*, *22*(10), 3749. https://doi.org/10.3390/s22103749

Rademaker, F., de Boer, A., Kupers, E., & Minnaert, A. (2020). Applying the contact theory in inclusive education: A systematic review on the impact of contact and information on the social participation of students with disabilities. *Frontiers in Education*, *5*, 602414. https://doi.org/10.3389/feduc.2020.602414

Rieffe, C., Broekhof, E., Eichengreen, A., Kouwenberg, M., Veiga, G., Silva, B. M. S. d., Laan, A. v. d., & Frijns, J. H. M. (2018). Friendship and emotion control in pre-adolescents with or without hearing loss. *Journal of Deaf Studies and Deaf Education*, *23*(3), 209–218. https://doi.org/10.1093/deafed/eny012

Rogat, T. K., Hmelo-Silver, C. E., Cheng, B. H., Traynor, A., Adeoye, T. F., Gomoll, A., & Downing, B. K. (2022). A Multidimensional Framework of Collaborative Groups' Disciplinary Engagement. *Frontline Learning Research*, *10*(2), 1–21. https://doi.org/10.14786/flr.v10i2.863

Schorr, E. A. (2006). Early cochlear implant experience and emotional functioning during childhood: Loneliness in middle and late childhood. *The Volta Review*, *106*(3), 365. https://doi.org/10.17955/tvr.106.3.m.572

Silva, B. M. S. d., Rieffe, C., Frijns, J. H., Sousa, H., Monteiro, L., & Veiga, G. (2022). Being deaf in mainstream schools: The effect of a hearing loss in children's playground behaviors. *Children*, *9*(7), 1091. https://doi.org/10.3390/children9071091

Stehlé, J., Voirin, N., Barrat, A., Cattuto, C., Isella, L., Pinton, J. F., Quaggiotto, M., van den Broeck, W., Régis, C., Lina, B., & Vanhems, P. (2011). High-resolution measurements of face-to-face contact patterns in a primary school. *PLoS ONE*, *6*(8), e23176. https://doi.org/10.1371/journal.pone.0023176

Stehlé, J., Charbonnier, F., Picard, T., Cattuto, C., & Barrat, A. (2013). Gender homophily from spatial behavior in a primary school: A sociometric study. *Social Networks*, *35*(4), 604–613. https://doi.org/10.1016/j.socnet.2013.08.003

Schwarz, G. (1978). Estimating the dimension of a model. *Annals of Statistics*, *6*, 461–464. https://doi.org/10.1214/aos/1176344136

Tsou, Y.-T., Kovács, L. V., Louloumari, A., Stockmann, L., Blijd-Hoogewys, E., Koutamanis, A., & Rieffe, C. (2024). School-based interventions for increasing autistic pupils' social inclusion in mainstream schools: A systematic review. *Review Journal of Autism and Developmental Disorders*, 1–24. https://doi.org/10.1007/s40489-024-00429-2

van der Straaten, T. F. K., Briaire, J. J., Dirks, E., Soede, W., Rieffe, C., & Frijns, J. H. M. (2021). The school career of children with hearing loss in different primary educational settings—A large longitudinal nationwide study. *Journal of Deaf Studies and Deaf Education*, *26*(3), 405–416. https://doi.org/10.1093/deafed/enab008

van Rossum, G., & Drake, Jr, F. L. (1995). *Python tutorial*. Centrum voor Wiskunde en Informatica.

Veiga, G., de Leng, W., Cachucho, R., Ketelaar, L., Kok, J. N., Knobbe, A., Neto, C., & Rieffe, C. (2017). Social competence at the playground: Preschoolers during recess. *Infant and Child Development*, *26*(1), e1957. https://doi.org/10.1002/icd.1957

Veiga, G., Ketelaar, L., de Leng, W., Cachucho, R., Kok, J. N., Knobbe, A., Neto, C., & Rieffe, C. (2017). Alone at the playground. *European Journal of Developmental Psychology*, *14*(1), 44–61. https://doi.org/10.1080/17405629.2016.1145111

Veiga, G., & Rieffe, C., (2018). Monitoring children's behaviors in their natural settings: Applying RFID sensors to study child development. In *Sage Research Methods Cases Part 2*. SAGE Publications, Ltd. https://doi.org/10.4135/9781526446435

Vriesema, C. C., & McCaslin, M. (2020). Experience and meaning in small-group contexts: Fusing observational and self-report data to capture self and other dynamics. *Frontline Learning Research*, *8*(3), 126–139. https://doi.org/10.14786/flr.v8i3.493

Wolters, N., Knoors, H. E., Cillessen, A. H., & Verhoeven, L. (2011). Predicting acceptance and popularity in early adolescence as a function of hearing status, gender, and educational setting. *Research in Developmental Disabilities*, *32*, 2553–2565. https://doi.org/10.1016/j.ridd.2011.07.003

Wolters, N., Knoors, H., Cillessen, A. H., & Verhoeven, L. (2014). Social adjustment of deaf early adolescents at the start of secondary school: The divergent role of withdrawn behavior in peer status. *Exceptional Children*, *80*(4), 438–453. https://doi.org/10.1177/001440291452724

Xie, Y. H., Potměšil, M., & Peters, B. (2014). Children who are deaf or hard of hearing in inclusive educational settings: A literature review on interactions with peers. *Journal of Deaf Studies and Deaf Education*, *19*(4), 423–437. https://doi.org/10.1093/deafed/enu017

Zaidman-Zait, A., & Dotan, A. (2017). Everyday stressors in deaf and hard of hearing adolescents: The role of coping and pragmatics. *Journal of Deaf Studies and Deaf Education*, *22*, 257–268. https://doi.org/10.1093/deafed/enw103

Zaidman-Zait, A., & Most, T. (2020). Pragmatics and peer relationships among deaf, hard of hearing, and hearing adolescents. *Pediatrics*, *146*(Supplement_3), S298–S303. https://doi.org/10.1542/peds.2020-0242J

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APPENDIX 1: Mean scores of social participation according to gender and hearing loss status.

	DHH (*M, SD*)		Hearing (*M, SD*)	
	Boys (*N* = 6)	Girls (*N* = 2)	Boys (*N* = 83–91)	Girls (*N* = 90–92)
% Schoolyard time in interactions[a]	–.44 (1.01)	–.87 (.24)	.03 (.98)	.02 (.80)
% Schoolyard N different partners[a]	.15 (.69)	.58 (1.55)	.18 (.80)*,†	–.17 (.96)
Peer acceptance[a]	–.21 (1.03)	–.37 (.29)	–.01 (.97)	.04 (1.00)
Mutual friendships[a]	–.56 (1.16)	.48 (.68)	.10 (1.05)	–.07 (.94)
Sense of connectedness—group integration	2.48 (.17)	2.50 (.50)	2.41 (.44)	2.37 (.49)
Sense of connectedness—peer intimacy	2.38 (.35)	2.07 (.50)	2.44 (.44)***, ††	2.71 (.33)

Note: Gender comparison within the hearing group.
[a]Standardized.
*p (*two-tailed*) $< .05$; ***p (*two-tailed*) $< .001$.
†$N = 173$, $U = 2965.5$, $p = .019$.
††$N = 181$, $U = 5621.5$, $p = .000$.

APPENDIX 2: Regression weights (standard error) examining group differences and changes across recess time in schoolyard number of partners, controlling for the mean number of partners each child's partners had contact with.

	Playground N partners Estimate (SE)
Over-time trajectory[a]	
Intercept	.12 (.04)**
Sex	–.03 (.01)***
Group	–.02 (.02)
Linear	.16 (.03)***
Quadratic	–
Cubic	–.04 (.02)*
N partners' partners	.14 (.08)
Intercept variance (subject = class)	.003 (.002)
Residual variance (repeated measures = time)	.02 (.001)***
Five-min segment	
Intercept	.08 (.04)*
Sex	–.03 (.01)***
Group	.02 (.03)
Segment	.01 (.003)***
Group × Segment	–.02 (.01)*
N partners' partners	.15 (.08)
Intercept variance (subject = class)	.003 (.002)
Residual variance (repeated measures = time)	.02 (.001)***

[a]Interaction effects are removed from the final model, hence not shown here.
* $p < .05$; ** $p < .01$; *** $p < .001$.