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ABSTRACT

Social connectedness at school is crucial to children's development, yet very little is known about the way it has been affected by school closures during COVID-19 pandemic. We compared pre-post lockdown levels of social connectedness at a school playground in forty-three primary school-aged children, using wearable sensors, observations, peer nominations and self-reports. Upon school reopening, findings from sensors and peer nominations indicated increases in children's interaction time, network diversity and network centrality. Group observations indicated a decrease in no-play social interactions and an increase in children's involvement in social play. Explorative analyses did not reveal relations between changes in peer connectedness and pre-lockdown levels of peer connectedness or social contact during the lockdown period. Findings pointed at the role of recess in contributing to children's social well-being and the importance of attending to their social needs upon reopening.

During March to April 2020, after the first outbreak of the Coronavirus pandemic (COVID-19), most countries worldwide temporarily closed schools to prevent further spread of the disease. This decision affected over 1 billion students around the globe (UNESCO, 2021). Since then, practices of full or partial school closures have been applied worldwide in response to local outbreaks and policies (UNESCO, 2021). The COVID-19 crisis has highlighted the crucial role of schools not only as sites for knowledge transmission, but mostly as fulfilling the socialization needs of young people (Colao et al., 2020). Social distancing, loss of physical contact with peers and teachers, and loss of daily school routines, increased the risk for social isolation. To date, very little is known about the effects of schools' closure on children's social well-being, not only during the lockdown period, but also when schools reopen, and children resume interactions with peers. After a long disruption in their educational and social lives, do children resume social connections as before, or are there changes in the way peer interactions are enacted or experienced?

Social connections at school and perceived sense of connectedness are critical predictors of mental and physical health, as well as psychosocial and academic adjustment (Diendorfer et al., 2021; Grapin, Sulkowski, & Lazarus, 2015; Jose, Ryan, & Pryor, 2012). Social isolation by itself is known to increase the risk for mental health problems such as depression and anxiety (Loades et al., 2020). Research shows that even during regular school holidays children display fewer physical activities and have fewer social contacts than during school terms (Chen & You, 2015; Eames, Tilston, & Edmunds, 2011; Olds, Maher and Dumuid,

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2019), and that they experience during the holidays more loneliness, social isolation, and boredom (Kromydas et al., 2022), especially if they are socially disadvantaged (Morgan et al., 2019). However, the school lockdown was much more extreme than that, as children were at home every day, with holiday and everyday community facilities closed. Unlike planned holidays, the lockdown measures (especially following the first COVID-19 outbreak) were usually enacted abruptly, leaving children little time to process the sudden changes. Besides, many children might have felt anxious about the crisis whereas they usually feel relaxed during the school holiday. Furthermore, children's mobility could be much more restricted during the lockdown period because of the COVID-19 measures, and in many countries, such as in the Netherlands, school closures lasted longer than the country's regular summer breaks. In the context of the first COVID-19 outbreak, recent reviews looking at children's social and emotional well-being (Manchia et al., 2022; Viner et al., 2021) indicated that school closures resulted in an increase in screen use, decrease in physical activity, and at times in significant increases in depressive and anxiety symptoms, especially for children and adolescents with additional vulnerabilities, such as deprived backgrounds. Upon returning to schools, the few studies that have been published have shown mixed findings with regards to children's mental health. Gallagher, Walsh, and McMahon (2020) found no changes in emotional and behavioral difficulties in primary school children when assessed before lockdown and after school reopening. Yet, other studies found increases in depressive symptoms or behavioral difficulties in primary school children and early adolescents (Pearcey, Shum, Waite, Patalay, & Creswell, 2020; Zhang et al., 2020). With regards to peer interactions, a recent study (Mitsven, Perry, Jerry, & Messinger, 2022), comparing preschoolers with and without hearing loss before and during COVID-19, did not find negative effects for classroom mask-wearing on children's vocal interactions with their teachers and peers. To the best of our knowledge, only one study has examined perceived social connections upon reopening; this was a study without comparable pre-lockdown assessments. Qvortrup, Lundtofte, Lomholt, Christensen, and Nielsen (2020) examined the perspectives of Danish primary school children ($N = 1227$) when returning to schools under conditions of partial reopening, focusing on their perceived friendships and sense of connectedness. Most of the children in their study (65%) felt that their relationships with friends remained the same as before the Coronavirus. Yet, 13% reported that their relationships were worse than before, and 22% reported that they were better. Similar results were obtained when asked about the community in their class. Further, most children (around 80%) felt some or all of the time understood, fitting in and not alone (Qvortrup et al., 2020).

The Qvortrup study provides important data about children's sense of connectedness during the reopening period. This insight could be further explored by comparing data obtained after the lockdown with comparable pre-lockdown data, and by further exploring the effects of full-schedule reopening. Further studies could also enhance our understanding of the variance in children's social experiences as indicated in Qvortrup study, by examining factors that may explain why for some children social connections did not change, while for others they worsened or improved. For example, there was evidence suggesting that pre-lockdown sense of connectedness with peers or with school was positively associated with mental well-being during the lockdown period (Widnall, Winstone, Mars, Haworth, & Kidger, 2020) and upon reopening (Widnall et al., 2021). Other studies, conducted with adolescents (Magson et al., 2021; Qi et al., 2020; Sabato, Abraham, & Kogut, 2021) or adults (e.g., Cantarero, van Tilburg, & Smoktunowicz, 2020; Nitschke et al., 2021), found a positive association between social network size (Cantarero et al., 2020; Nitschke et al., 2021; Sabato et al., 2021) or sense of connectedness during the lockdown (Cantarero et al., 2020; Magson et al., 2021; Qi et al., 2020), and mental well-being during that time-period. In all of these studies, it is unknown to what extent social connectedness before or during the lockdown predicts social connectedness at school upon reopening.

To date, our knowledge on children's social connections upon reopening is based on their perceived sense of connectedness with peers (Qvortrup et al., 2020). Although self-reports provide important information on children's subjective experiences, our understanding of pre-post lockdown changes in peer connectedness would benefit from combining self-reports with other sources of information, such as peer evaluations or field observations. As will follow, a growing body of research points at the school's playground as a major site both for the development of peer connectedness (e.g., McNamara, Colley, & Franklin, 2017) and for the application of innovative sensor measures of peer interactions (Veiga et al., 2017).

The school's playground provides rich opportunities for interactions and free social play with same-age peers and as such plays a crucial role in promoting children's socio-emotional development and well-being (McNamara et al., 2017; Murray & Ramstetter, 2013). It is during free play that children learn how to cooperate, negotiate, manage conflicts, explore, and take risks, become independent, and learn about themselves and others (Jarvis, Newman, & Swiniarski, 2014). Indeed, social connections at the school's playground have been shown to positively associate with the child's social competence (Veiga, de Leng, et al., 2017). Outdoor free play with peers promotes physical activity, emotional skills such as self-regulation or sense of agency, social skills and prosocial attitude, reduction of stress and building up executive functions, thereby promoting learning skills and academic performance (Murray & Ramstetter, 2013; Yogman et al., 2018). Recently, recess time has been strongly advocated by child experts and researchers, pleading stakeholders not to eliminate it upon school's reopening (Clevenger & Pfeiffer, 2020; London, 2021), and calling for "harnessing recess and the power of play to rebuild the school community and support the well-being of their students" (London, 2021, p.1).

While participating in outdoor recess time has been investigated in relation to individual developmental outcomes, there is little empirical knowledge about the dynamics of peer interactions at the playground, such as their position in the social network or their involvement in social play. Recently, Engelen et al. (2018) developed an observation scheme which focuses on the playground as an entity and enables to quantitatively map different types of playground activities and their frequencies. This observation scheme has proved to successfully track changes in children's social, physical, and play-related activities at the playground (Engelen et al., 2018). In addition, during the last decade a growing number of studies have applied wearable sensors to assess playground interactions (e.g., Heravi, Gibson, Hailes, & Skuse, 2018; Stehlé et al., 2011; Veiga et al., 2017). Attached to children's shirts, small light-weighted sensor badges allow children to play naturally without intruding their space and affecting their behaviors (Veiga, de Leng, et al., 2017). Such sensors detect interactions within very short time frames between children who are in physical proximity, providing a large amount of continuous spatio-temporal data of simultaneous interactions within a large group. This is subsequently analyzed to address innovative research questions, such as the relation between playground behaviors and social competence (Veiga, de Leng, et al., 2017), same-sex preference and group transitivity (Messinger et al., 2019; Stehlé, Charbonnier, Picard, Cattuto, & Barrat, 2013), the effect of interventions on social connectedness at individual and at group levels (Eichengreen et al., 2023; Gibson, Hailes, Heravi, & Skuse, 2018; Heravi et al., 2018), social inclusion (Fasano et al., 2021); and in this study - the social effect of schools' closure and reopening.

The present study

The goal of this study was to explore changes in peer connectedness following school closure and reopening, and factors that may associate with these changes, through a pre-post lockdown design. We focused on a case study of two primary-school classes (ages 8–11 years) who spent recess together at the playground. The age-range of our participants is defined as preadolescence or early adolescence (Crone & Dahl, 2012;

Sawyer, Azzopardi, Wickremarathne, & Patton, 2018), a period when significant pre-pubertal bodily, neurological, cognitive, and socio-emotional changes start to take place. Social cognitions become more complex during preadolescence, and the peer group is rapidly becoming central to the child's emerging individuality and social development, including heightened sensitivity to peer acceptance/rejection (Crone & Dahl, 2012; Morrow, Hubbard, & Sharp, 2019). This age-group is therefore potentially highly sensitive to the effects of school-closure on their social interactions. At the same time, while their interactions increase in complexity, preadolescents are still enjoying and displaying a variety of play activities at the school playground (Blatchford, 1998), which makes their playground behaviors suitable for a rich exploration. The social connectedness of our group was therefore examined in several ways, as follows.

First, to examine the extent to which social connectedness among children changes before and after lockdown, we compared between two recess assessments. We used sensors, playground observations, peer nominations, and self-reports to measure changes in several aspects of peer connectedness, including: (1) playground interactions during recess, including the time children spent in interactions, the number of interaction partners, their centrality in the playground social network (i.e., playground closeness centrality), and their involvement in various playground activities; (2) peer preferences, including the number of received nominations (i.e., in-degree) as preferred playmates, and their centrality in the nomination-based social network (i.e., nomination-based closeness centrality); and (3) children's sense of social connectedness as measured by self-reported sense of loneliness.

Next, we examined potential factors which could explain variance in post-lockdown changes in social connectedness. This topic has not been examined before, yet studies which focused on mental well-being suggested that pre- and during-lockdown connectedness with peers were significant positive predictors (e.g., Magson et al., 2021; Qi et al., 2020; Sabato et al., 2021; Widnall et al., 2021). We explored whether: (1) pre-lockdown connectedness (i.e., pre-lockdown playground interaction, peer preference, and sense of connectedness), and (2) the level of during-lockdown peer contact, predicted changes in peer connectedness upon school reopening. Due to the lack of studies focusing on social connections upon reopening as an outcome, all examinations in this study were exploratory and no specific directions were hypothesized.

Methods

Participants

This study was part of a larger research on the impact of a playground intervention on children's social connections, which took place in one primary school in the Netherlands (Eichengreen et al., 2023). The children belonged to two classes who attended the playground together during the assessments. The assessments taken for this study were conducted before the application of the intervention started. The first assessment (i.e., T1) took place in the first week of March 2020, shortly before the lockdown started on March 16th, and the second (i.e., T2) took place in the second week of June, 14 weeks later, right after the school returned to full schedule on June 8th. In-between these assessments the school remained closed for two months, followed by one month of partial opening, where classes were split into half and each half-class attended school for three days a week. The second assessment took place shortly after the school returned to full educational setting (full class size, whole week attendance). About six weeks after reopening, on July 18th, all schools in that region started their 6-weeks-long summer holiday. The total sample of our study included 43 children (Mean age = 9.8 years, range = 8.32–11.75), 46.5% of whom were females. All participants contributed data for at least one assessment, thereby all were included in playground observations. Missing cases in which complete data could not be provided in both assessments were not included in examination of individual differences between assessments. Reasons for missing cases included school drop-out after the first assessment, parental consent given only after the first assessment, or child's illness. In total, complete data for both assessments included self-reports ($N = 34$, 79% of all participating children), sensor data ($N = 30$, 70% of all participating children; with high overlap of 87% and 97% with self-reports and peer nomination data respectively), and peer nomination scores ($N = 37$, 86% of all participating children). Little's MCAR test showed that data were missing completely at random ($p = 1.00$). Table 1 presents consent rates and data on missing cases.

Materials

Playground interactions

Time spent in social interactions. The time children spent in social interactions at the playground was measured by computing per child, a percentage score of the time the child spent in social interactions, normalized by the total time the child was detected during recess. This was measured by wearable sensors, using OpenBeacon Radio Frequency Identification Devices (RFID) (Cattuto et al., 2010). RFID badges identify tags in close proximity based on low-energy-Bluetooth. Each tag is worn by an individual child at the playground, measuring face-to -face interactions at an approximate orientation range of 30–65 degrees within an approximate distance of up to 1.5 m (Cattuto et al., 2010; Elmer, Chaitanya, Purwar, & Stadtfeld, 2019). Every second, when an interaction between two badges is detected, a signal is sent to a receiving "reader" located at the borders of the playground. To avoid loss of sensitivity due to fluctuations in signals 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 and a period of up to 20 s elapsed and then they were registered as interacting again, they were assumed to interact together the entire time. We calculated the percentage of time each child spent in interactions in relation to the total time the child's badge was identified by the RFID reader. By taking the total identification time for each badge rather than the duration of the break as a reference point, the sensor data affords more accurate comparisons between children.

Number of different partners. A degree centrality measure (Diestel, 2005) was used to calculate the number of partners at an individual level, via RFID badges (Cattuto et al., 2010). It is calculated as a percentage score, measuring the number of different partners each child interacted with, normalized by the maximum possible partners, i.e., for a group with n members, the count of different interacting partners is normalized by $(n-1)$. Degree centrality 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.

Centrality in the social network based on time and interacting partners. A closeness centrality measure was computed for each child to measure the level of network connectivity with all other children at the playground, based on face-to-face contacts as measured via RFID badges.

Table 1
Participation rates and missing cases.

	Class 1	Class 2
Total N in class	26	25
N attending regularly recess on this day of the week	26	19
N participating (positive consent)	25	18
Participation rate out of total N in class/attending recess	96%/ 96%	72%/ 95%
Missing self-reports	4	5
Missing sensors	6	7
Missing received nominations scores	1	5

Missing cases are defined as cases in which data were missing at least at one assessment.

The closeness centrality measure is a powerful measure in social network analysis which takes individuals as well as their links and connections into account to analyze data structures in the form of a network (Freeman, 1978). In the playground context, the closeness centrality is inversely proportional to the average shortest path, created by proximity connections, to travel from one child to all other children at the playground (Jorge et al., 2019). We uniquely computed closeness centrality on a weighted graph for child *u* as follows:

$$Closeness\ centrality\ (u) = \frac{n-1}{\sum_{v=0}^{n-1} d(u, v, weight_{sensor})} \quad (1)$$

where *n* is the total number of children that can reach child *u*, and $d(u, v, weight_{sensor})$ is the shortest path between child *u* and child *v*. In our study, the shortest path is applied to a weighted graph in which the weight per pair *(u, v)* (proximity connections between the children) is defined as follows:

$$weight_{sensor}(u, v) = \frac{Common\ detection\ time\ (u, v)}{Time\ spent\ in\ interaction\ (u, v)} \quad (2)$$

Where common detection time between child *u* and child *v* (i.e., the total time both children, *u* and *v*, were identified at the playground at the same time points) is divided by the total time each dyad (*u* and *v*) spent in interaction with each other. This definition guarantees that the cost of traveling from one child to another for those with higher dyadic interaction time is lower and incorporated into the calculation of the closeness centrality. This computation enables to combine both the elements of time and interacting partners in a single measure of network centrality, ensuring that those with higher interaction time and more partners are more connected to the network.

Playground activities

Playground activities were measured at a group level through observations, using the System for Observing Outdoor Play (SOOP; Engelen et al., 2018). We measured the proportion of children involved in each activity by dividing the number of children observed in this activity by the total number of children observed during recess. The SOOP is an observation scheme developed to scan the playground and quantify different types of activities in a systematic and comprehensive way. The playground is divided in advance into four parts. In our study, two research students observed simultaneously each part for one minute (one observation unit) in a clockwise manner. They repeated these observations continuously throughout the whole recess time. At each observation unit, the observers coded activity types and counted the number of children participating in each type of activity. We classified playground social behaviors based on the Howes Peer Play Scale (Howes & Matheson, 1992) as used by Mahony, Hyndman, Nutton, Smith, and Te Ava (2017) and adjusted to our research aims. The following categories were included: solitary no play (e.g., observing, eating or moving without interactions with other children), solitary play (playing alone or in parallel to others without interacting with them), social no play (e.g., talking), social play (e.g., any playful joint activity, from imaginary play or joint drawing to rough and tumble or soccer), conflict (arguing, fighting or any negative interaction between children equal in power), and bullying (physical or verbal bullying, or other forms of social rejection when children were not equal in power). Behaviors were classified regardless of children's proximity. It could be, for example, that two children were in physical proximity, thus registered as interacting by the sensors, yet both were classified as not interacting by the observers (e.g., solitary no play). In this way, observations contributed a qualitative perspective on children's interactions. Unclear topics (e.g., how to code specific behaviors) were discussed between the observers and the researchers after each session and resolved with full agreement. The observers coded recess as part of baseline measures for an intervention project, and therefore were unaware of the goal of the present study. An interrater reliability was computed for the most frequently observed categories (social play and social no play) to avoid inflation in interrater agreement. We used Intraclass Correlation Coefficient (ICC) for average measures in a two-way mixed effects model. Results indicated high interrater reliabilities at both time points (ICC = 0.893 at T1 and 0.883 at T2).

Peer preferences

Social connectedness based on peer nominations. Children's social preferences at the playground were obtained through peer nominations (Pijl, Frostad, & Flem, 2008). While this study focused on the context of recess, recess nominations tend to overlap highly with other social contexts such as friendship nominations (Pijl et al., 2008), making it likely that recess nominations indicate on relationships which exceed the playground context. Each child was asked to name the peers with whom they mostly liked to play during recess. Children could name playmates from both classes. To avoid endless lists that contain weak relationships, the semi-fixed choice of maximum five was applied (e.g., Pijl et al., 2008). For each child, we computed: (1) th*e number of received nominations the child received*, and (2) *nominations-based closeness centrality score* (Anderson, Locke, Kretzmann, & Kasari, 2016). The closeness centrality was calculated on a directed-weighted graph of nominations to measure the strength of connectivity a child had with the rest of the playground mates, based on all direct and indirect nominations which connected this child with the rest of the children. The same closeness measure as defined in eq. (1) is used for the peer nomination data, in which the weight for a nomination between child *u* and child *v* i.e., edge (u,v) is defined as follows:

$$weight_{PN}(u,v) = \begin{cases} 1, & One-way nomination \\ 0.5, Mutual nomination & \end{cases} weight_{PN}(u,v) = \begin{cases} 1, & One-way nomination \\ 0.5, Mutual nomination & \end{cases} \quad (3)$$

This definition guarantees that the cost of traveling from one child to another for those with mutual nomination is lower (= 0.5) than those with one-way nomination (= 1) and is incorporated into the calculation of the closeness centrality. As a result, those with higher number of mutual nominations will receive a higher closeness score because of having more access with lower cost to the network.

Sense of social connectedness

Sense of loneliness. Loneliness is often used as an inverse measure of sense of social connectedness (Diendorfer et al., 2021). We used the Children's Loneliness Scale (CLS; Asher, Hymel, & Renshaw, 1984; translated into Flemish by Maes, van den Noortgate, Vanhalst, Beyers, & Goossens, 2017), a self-report measure of social dissatisfaction and loneliness at the school context (Asher & Wheeler, 1985). The CLS consists of 24 items of which 16 measure loneliness (e.g., *"At school I have no one to play with"*, reversed scored), and eight serve as filler items (e.g., "*I like to read*"). Respondents were asked to rate their responses to CLS items on a 5-point scale from 1 (*"not at all"*) to 5 (*"always"*). After reverse scoring, higher score indicates on less feelings of loneliness. Cronbach alpha reliability of the CLS has been reported as good for both the English and the Flemish versions (Asher & Wheeler, 1985; Maes et al., 2017). In this study internal consistencies were comparably good at both time points (α = 0.80/0.89 at T1/T2 respectively).

Social contact during lockdown

In the post-lockdown self-report, we included a question measuring the degree of social contact the children had with their friends during the school closure (*"Did you have contact or meet up with your friends from class when you could not go to school?"*). Respondents were asked to rate their response on a 3-point scale (0 = *no*, 1 = *a little*, 2 = *yes*).

Procedure

The study was approved by Leiden University Ethics Committee. Written consent forms were signed by parents of all participating children. The assessments took place at the same day of the week at both time points. No other classes attended the playground during the assessments except for the participating classes. After receiving information about the project from the researchers, children filled out questionnaires in the classroom in the morning. On the same day, they put on sensor badges shortly before they went to the playground for lunch recess. At the end of recess, they returned the badges to the researchers. Recess lasted approximately half an hour each assessment. During recess, student researchers stood at the borders of the playground and unobtrusively coded playground activities. Sensor data were recorded by a computerized receiver located at the border of the playground.

Data analyses

The raw sensor data was first preprocessed using Python 3.9 (van Rossum & Drake Jr, 1995). The NetworkX 2.6.3 Python package was used for visualization. Statistical analyses were performed using SPSS version 27.0 (SPSS Inc., Chicago, IL, USA).

To examine changes in social connectedness before and after lockdown, T2-T1 comparisons were conducted for all aspects of social connectedness. First, changes in playground individual-level interactions (i.e., time spent in interactions, number of different partners, and playground closeness centrality) were analyzed using three paired samples *t*-tests/Wilcoxon Signed-Rank tests (according to the distribution of scores). Group-level changes in the proportions of involvement in playground activities were analyzed using six Pearson Chi-Square tests.

Next, a Pearson Chi-Square test was used to test the change in the distribution of the number of received nominations, and a paired Wilcoxon Signed-Rank test was used to test individual changes in closeness centrality based on peer nominations.

Third, change in sense of loneliness was analyzed by a Wilcoxon Signed-Rank test.

Lastly, to examine the extent to which pre- and during-lockdown connectedness factors are associated with pre-post changes in social connectedness, three linear mixed models (LMMs) (Singer & Willett, 2003) were conducted for exploratory purposes. LMM was used because it can account for the methodological concerns with regression to the mean and mathematical coupling that are often seen when changes are regressed/correlated with baselines (Tu and Gilthorpe, 2007). For each domain of social connectedness, we selected a variable that most straightforwardly represents close connections with peers. Thus, time in interactions was selected over number of partners, as previous research has shown that longer duration of interactions and smaller peer groups were related to better social competence (Veiga, de Leng, et al., 2017); and a direct measure of nominations was selected over closeness centrality, as the latter also accounts for indirect relations with the rest of the group. The dependent variables for the 3 LMMs were therefore interaction time at the playground, number of received nominations, and sense of loneliness, respectively, with a two-level structure (time points nested within participants). We started with adding fixed intercept and fixed effects for Time (0 = pre-lockdown; 1 = post-lockdown), During-Lockdown Contact [recoded into 0 = little (previously 0/1); 1 = a lot (previously 2)], and the interaction of Time x During-Lockdown Contact, along with a random intercept and a random slope for Time. By examining the estimated correlation between the random intercept and the random slope for Time, we determined the effect of pre-lockdown level of connectedness on the pre-post changes (Blance et al., 2005). Control variables (age, gender) were also added to the models. They did not improve the model fits and thus were excluded from the models and are not reported.

We used multiple imputations (MI; van Buuren, 2012) to correct for the potential bias and loss of power which could result from missing values in the individual independent variables (Netten et al., 2017). We thus handled missing values at T1 based on participants' characteristics and relations in the data among participants (Schafer & Graham, 2002). The variables included for the estimation of imputed data were age, gender, and all sensors, peer nominations and self-reports variables (Sterne et al., 2009). The pooled results are reported. A significance level of $p < .05$ was considered. In cases of multiple testing, Bonferroni corrections were applied based on the number of analyses required. The corrected significance levels were specified under Tables 2 and 3.

Results

Differences in social connectedness between pre- and post-lockdown measures

Table 2 presents the mean scores at T1 and T2 (pre- and post-lockdown respectively) in social connectedness based on playground interactions, playground activities, peer preferences, and subjective reported sense of loneliness. Visualizations of the social networks at both time points, based on sensor data and peer nominations, are presented in Figs. 1 and 2.

Results showed at T2 more individual time spent in social interactions ($t(29) = 2.77$, $p = .010$), a broader variety of interaction partners ($t(29) = 6.75$, $p = .000$), and a higher level of connectivity to all playground mates as measured by closeness centrality ($Z(30) = 3.63$, $p = .000$), compared to T1 (see Fig. 1). Findings also indicated a decrease in the proportions of social activities which were not play ($X^2(1, 595) = 11.25$, $p = .001$) and an increase in the proportions of social play ($X^2(1, 595) = 13.39$, $p = .000$) from T1 to T2, based on group observations.

Findings based on peer nominations indicated a change in the

Table 2
Mean scores (standard deviations) of study variables at T1 and T2.

Social connectedness variables	Mean scores (SD)		Test value
	T1	T2	
Playground interactions: Sensors[a]			
% Time spent in interactions	48.24 (22.80)	66.40 (19.90)	$t = 2.77$*
% Number of different partners	30.69 (13.03)	59.80 (17.05)	$t = 6.75$***
Closeness centrality weighted with dyadic interaction time	0.05 (0.01)	0.07 (0.02)	$Z = 3.63$***
Playground activities: Group observations[b]			
% Solitary no play	7.89	6.88	$X^2 = 0.241$
% Solitary play	3.11	2.34	$X^2 = 0.515$
% Social no play	33.73	21.17	$X^2 = 11.25$**
%Social play	54.31	69.35	$X^2 = 13.39$***
% Conflict	0.96	0.26	$X^2 = 1.31$
% Bullying	0	0	NA
Peer preferences[a]			
Number of received nominations	3.16 (1.50)	3.43 (1.79)	$X^2 = 70.05$*
Closeness centrality weighted with mutual nominations	0.28 (0.08)	0.31 (0.08)	$Z = 2.29$*
Sense of social connectedness[a]			
Sense of loneliness (higher score = less loneliness)	4.06 (0.49)	4.20 (0.55)	$Z = 1.93$

T1 = before the lockdown; T2 = after the lockdown.
* *p (two-tailed)* < 0.05; ** $p < .01$; *** $p < .001$.
Significance level is adjusted for multiple testing: $p < \alpha/3 = 0.017$ for Playground interactions; $p < \alpha/6 = 0.008$ for Playground activities; $p < \alpha/2 = 0.025$ for Peer preferences.
[a] Measured at an individual level.
[b] Measured at a group level.

Table 3
Regression weights (standard error) from linear mixed models examining the effects of T1 and during-lockdown social connectedness on T2-T1 changes in social connectedness (pooled results after multiple imputations).

	% Time spent in playground interactions (sensors)		No. received nominations		(Less) Sense of loneliness	
Parameter	Estimate (SE)	p value	Estimate (SE)	p value	Estimate (SE)	p value
Fixed effects						
Intercept	0.51 (0.04)	< 0.001	3.10 (0.28)	< 0.001	4.01 (0.09)	< 0.001
Time[a]	0.11 (0.06)	0.041	0.13 (0.27)	0.638	0.01 (0.08)	0.867
During-lockdown contact[b]	−0.05 (0.06)	0.385	0.13 (0.43)	0.767	0.12 (0.14)	0.419
Time x During-lockdown contact	0.14 (0.08)	0.102	0.26 (0.40)	0.524	0.26 (0.12)	0.031
Random effects						
Residual	0.04 (0.01)	< 0.001	0.50 (0.29)	0.082	0.06 (0.03)	0.045
Intercept (Var = subject)	-[c]	–	1.42 (0.41)	< 0.001	0.16 (0.04)	< 0.001
Time (Var = subject)	–	–	0.73 (0.56)	0.192	0.03 (0.05)	0.528
Correlation Intercept-Time	–	–	0.212	0.172	0.109	0.487

N = 43. Adding age and gender did not improve the models, and thus those results are not reported here. Independent variables were considered having an effect when p (two-tailed) $< \alpha/3 = 0.017$.
[a] Time was coded as 0 = pre-lockdown; 1 = post-lockdown.
[b] During-lockdown contact was coded as 0 = little; 1 = a lot.
[c] Adding random effects caused the final Hessian matrix to be non-positive, indicating that the random effects could be redundant.

distribution of in-degree nominations, with more received nominations (X^2 (48, 37) = 70.05, p = .021), and an increase in closeness centrality (Z (37) = 2.29, p = .022) at T2 than at T1 (also see Fig. 2). Feelings of loneliness did not change across time points.

Factors associated with changes in social connectedness

Table 3 shows the results of the LMMs. No significant correlations were found between the random intercept (baseline levels) and the random slope for Time (changes from T1 to T2) for time in playground interactions, received nominations and sense of loneliness. Level of contact during lockdown did not have an effect on any of these variables. Correlations between all pre-, during- and post-lockdown social connectedness variables are presented in Table 4. Negative correlations were found between T1 and T2 levels of sensor variables (time in interactions, number of different partners and closeness centrality). Positive correlations were found between T1 and T2 levels of peer nominations variables (number of received nominations and closeness centrality) and between T1 and T2 levels of sense of loneliness. Positive correlations were also found between level of contact during the lockdown period and peer-nominations closeness centrality or sense of loneliness at T2. Subsequent LMMs analyses of closeness centrality variables are presented as a supplement material (Appendix 1).

Discussion

This case study was the first to compare between children's social connectedness before COVID-19 lockdown and after school returned to full schedule. The increases found in the time children spent in playground social interactions, in the variety of partners they interacted with, in the extent to which each child was connected to all other children as measured by closeness centrality, and in the proportions of social play out of their social activities, all suggested that after such a long separation from their peers children were eager to meet and play with each other. While some studies suggested no changes in children's mental well-being or friendship relations upon reopening (Gallagher et al., 2020; Qvortrup et al., 2020), our focus on playground interactions revealed an important dimension in children's social lives, i.e., their willingness to interact and play with their peers, which seemed to increase upon full reopening. Previous research has suggested that in times of instability, such as when entering middle school, play is used by preadolescents to develop friendships which will help them reduce uncertainty and support adjustment to school (Blatchford, 1998). Similarly, returning to school after a first long lockdown, while trying to adjust to a new era of coping with COVID-19, may increase in children both social longings and feelings of confusion or uncertainty. An increased use of play as a 'social glue' may have been an adaptive strategy our participants adopted to fit in this new reality. The important role of school recess in fulfilling their social needs (London, 2021) is therefore highlighted by this study's findings, particularly in the context of post-lockdown return to full academic routine.

Contrary to objective measures of playground behaviors and external evaluations of peer preferences, the increase at T2 in self-reported sense of connectedness (inverse of loneliness) was nonsignificant. This may be explained by a ceiling effect created by an already high pre-lockdown sense of connectedness (M = 4.06; SD = 0.49), with >60% of the children scoring on the Mean score or above. These findings emphasize the importance of combining several sources of information about children's social connections rather than self-reports alone for obtaining a more holistic perspective on their social connectedness.

Our data suggested that during the unique period of school reopening a restart had occurred to a certain degree in children's social connections. Compared to the pre-lockdown assessment, upon full reopening children interacted more with different partners at the playground, and more children were nominated as playmates by more peers. The social network became more cohesive, as closeness measures indicated. This change in network cohesivity may have been related to the group's increased engagement in social play, because, unlike free conversation, play often relies on set-up rules or objects which may help re-establish shared interests/experiences between children who are not close friends. Play and games in particular help establish group belonging and local peer culture (Evaldsson & Corsaro, 1998). The integration of observations with sensors findings suggests that while the overall high proportion of playground social activities did not change, after reopening a larger portion of these interactions took the form of a play, involving larger group sizes, which may have provided more interaction opportunities. Schools who are interested in harnessing recess to rebuild school's community and children's well-being, as London (2021) suggested, may use this temporary social flexibility and eagerness as a starting point for interventions aiming at facilitating social participation for all children. It should be noted that preliminary checks did not reveal significant effects for pre-lockdown levels of social connectedness, or level of social contact during the lockdown period, on changes from before to after the lockdown in social connectedness. However, significant correlations between pre-, during-, and post-lockdown aspects of social connectedness suggest that this issue merits further investigation with larger samples.

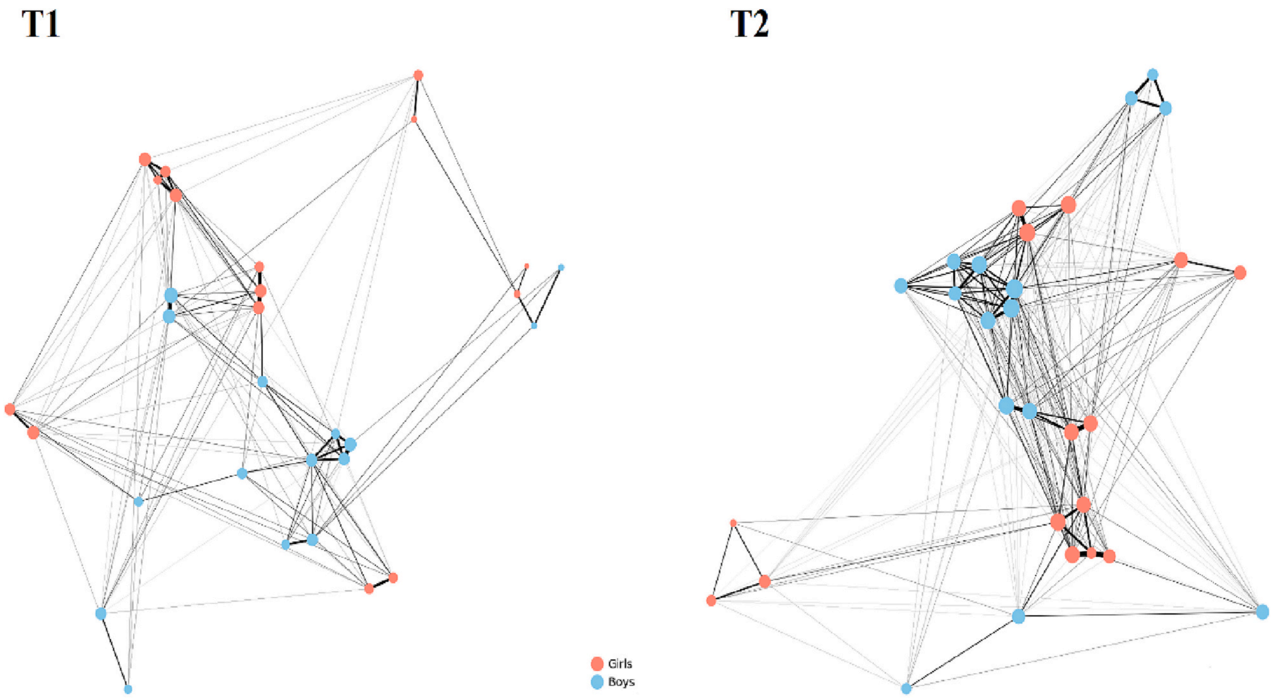

Fig. 1. Social networks at the playground before and after lockdown, based on sensor data.
T1 = before the lockdown; T2 = after the lockdown; Distance between every pair of nodes (children) and the thickness of the edge between the nodes are based on the percentage of time these two children were interacting with each other, out of the total time they were both detected at the same time points during recess. The more time they spent together the thicker the edge between the nodes is and the more closely the nodes are positioned. The size of the node is based on the number of different partners the child interacted with, with larger size indicating a broader variety of interaction partners.

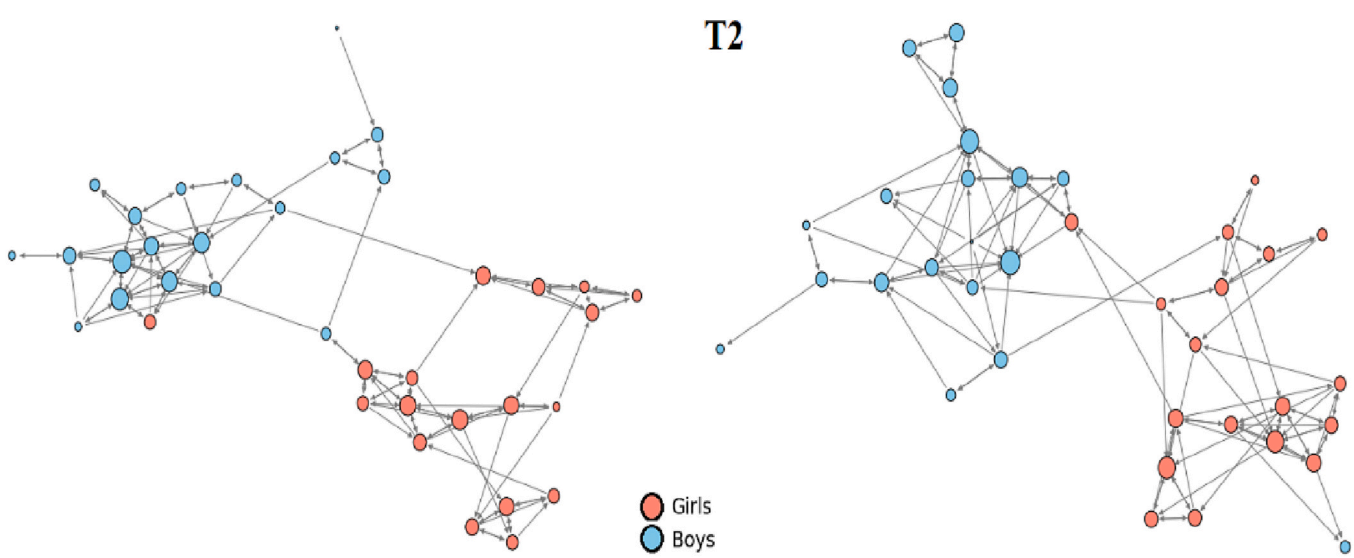

Fig. 2. Social network based on received peer nominations for playground playmates before and after lockdown.
T1 = before the lockdown; T2 = after the lockdown. Distance between every pair of nodes (children) is based on received in-degree nominations for playground mates, weighted by mutual nominations. The direction of the nomination is indicated by an arrow. The size of the node is based on the number of nominations each child received, with larger size indicating a larger number of nominations received.

Limitations and suggestions for future research

This research is based on a small-scale exploratory case study, thereby only outlining ideas and suggestions for future research which could examine their robustness. Longitudinal research is needed to examine the duration of the post-lockdown changes found in this study in social interactions and social play, e.g., examine whether these changes are short-lived or develop into long-lasting changes in children's social networks. Comparison between different types of post-lockdown reopening (full, partial, full after partial) and to school reopening that happens under ordinary conditions, such as summer or long holiday breaks, would contribute to examining the unique effects of the lockdown context. Longitudinal designs in particular can contribute to exploring further personal and contextual factors that could explain differential effects of schools' closure (Viner et al., 2021). For example, although during-lockdown contact with peers was not found in this

Table 4
Spearman Correlations between pre-, during-, and post-lockdown social connectedness variables (pooled results after multiple imputations).

T2 T1	% Time spent in interactions (sensors)	Number of different partners (sensors)	Closeness centrality (sensors)	No. received nominations (PN)	Closeness centrality (PN)	Sense of loneliness[a]	During-lockdown contact
% Time spent in interactions (sensors)	−0.414*	−0.113	−0.301	0.007	0.035	−0.106	−0.063
Number of different partners (sensors)	.-441*	−0.242	−0.426*	−0.242	−0.162	−0.191	−0.169
Closeness centrality (sensors)	−0.347	−0.172	−0.302	−0.126	−0.187	0.034	−0.021
No. received nominations (PN)	0.199	0.387*	0.287	0.550**	0.371*	0.269	0.034
Closeness centrality (PN)	0.142	0.373	0.235	0.049	0.449*	0.239	0.128
Sense of loneliness[a]	−0.152	0.027	−0.300	0.249	0.263	0.634**	0.292
During-lockdown contact	0.103	0.153	0.125	0.188	0.351*	0.426*	

$N = 43$. *p *(two-tailed)* < 0.05; **$p < .01$.
[a] Higher score = less loneliness.

study as uniquely related to changes in peer connectivity, other factors may be related such as the context of peer contact (e.g., online lessons, outdoor play) or the quality of family or school support, before, during or after the school's closure. Furthermore, Widnall et al. (2021) recently found that students who felt poorly connected to school before the lockdown may experience higher levels of anxiety on returning to school. It is therefore necessary to examine the extent to which the current findings are also applicable to children with various needs, such as children with disabilities or other members of minority groups, and the possible individual differences in the effects of school reopening. The possible relation between individual baseline and change levels of social connectedness needs further investigation, with repeated measures designs that optimally involve several large comparison groups, to enable controlling for issues such as regression to the mean and mathematical coupling. Last but not least, this study was conducted when the Netherlands enacted the first hard lockdown. Since then, aside from multiple partial lockdowns, evening curfews, and other measures for restricting social contacts, two other hard lockdowns were enacted in the Netherlands (from 16 December 2020 to 17 January 2021; from 19 Dec 2021 to 10 Jan 2022), when all schools were closed. The cumulative and long-term impacts of the pandemic on children's mental wellbeing, psychosocial development and sense of connectedness are yet to be seen, and need to be investigated by large-scaled longitudinal studies following children's development throughout the different phases of the pandemic.

Conclusion

The exploratory findings of this case study suggested that children interacted and played together more after a COVID-19 school closure when compared to pre-lockdown period, while their reported sense of loneliness did not change. It may be that children were more eager to interact socially after a long lockdown and separation from peers, suggesting that their social needs need to be attended when schools are planning academic schedule upon reopening. Space for outdoor play and recess time should be prioritized because outdoor social play supports children's social development, mental well-being and learning capacities (Yogman et al., 2018). Our findings suggested that upon reopening social networks become more flexible and cohesive, which may be harnessed by schools for further mobilization of sense of connectedness and well-being for all children.

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Declaration of Competing Interest

None.

Data availability

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.

Appendix 1. Regression weights (standard error) from linear mixed models examining the effects of T1 closeness centrality and during-lockdown social connectedness on T2-T1 changes in closeness centrality (pooled results after multiple imputations)

	Closeness centrality (sensors)		Closeness centrality (nominations)	
Parameter	Estimate (SE)	*p* value	Estimate (SE)	p value
Fixed effects				
Intercept	0.05 (0.002)	< 0.001	0.27 (0.02)	< 0.001
Time[a]	0.02 (0.004)	< 0.001	0.02 (0.02)	0.359
During-lockdown contact[b]	−0.002 (0.003)	0.607	0.03 (0.02)	0.136
Time x During-lockdown contact	0.01 (0.01)	0.145	0.03 (0.03)	0.195
Random effects				

(*continued on next page*)

(*continued*)

Parameter	Closeness centrality (sensors)		Closeness centrality (nominations)	
	Estimate (SE)	*p* value	Estimate (SE)	p value
Residual	0.0001 (0.00002)	< 0.001	0.003 (0.0007)	< 0.001
Intercept (Var = subject)	-[c]	–	0.002 (0.001)	0.024
Time (Var = subject)	0.0001 (0.00006)	0.017	-[c]	–
Correlation Intercept-Time	–	–	–	–

N = 43. Adding age and gender did not improve the models, and thus those results are not reported here.
[a] Time was coded as 0 = pre-lockdown; 1 = post-lockdown.
[b] During-lockdown contact was coded as 0 = little; 1 = a lot.
[c] Adding the random effect caused the final Hessian matrix to be non-positive, indicating that the random effect could be redundant (i.e., very little individual differences in the intercept or slope for Time). Hence, there was no clear effect of baseline closeness centrality on the pre-post changes in closeness centrality, whether measured by sensors or by peer nominations.

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