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Measuring changes in face-to-face interaction between teachers and students using a sociometric sensor device after teacher training

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Introduction: Teacher training (TT) was developed to improve teachers' skills in interacting with students with neurodevelopmental disorders. Teachers can also apply these skills to students without neurodevelopmental disorders in their classrooms. Therefore the interaction between teachers and students would change before and after the TT. However, prior studies have not utilized objective tools to assess the changes in interactions caused by TT interventions. In this study, a wearable sociometric sensor device was used to assess the changes in face-to-face interactions during a group classroom activity to provide objective measures of interactions.

Methods: We evaluated face-to-face interactions using sociometric devices in six classes, a total of six teachers and 158 elementary school students, during a group activity task. An evaluation of teacher-student interactions by video recording was also used to examine the directions of changes in interaction time between the sociometric device and video recording.

Results: The changes in face-to-face interaction time between teachers and students were in the same direction in five of six teachers. The TT intervention did not significantly affect the interaction time in the current study.

Discussion: Based on the results, a wearable sociometric sensor device can serve as an objective measure for detecting changes in classroom interactions.

KEYWORDS

teacher training, sociometric sensor device, behavioral therapy, neurodevelopment disorders, elementary school

1 Introduction

Teacher–student relationship has been a primary focus of educational research due to its impact on students engagement and outcomes. Previous studies have indicated that it is crucial for student school engagement, academic performance, school adjustment, and lower mental health problems (Baker et al., 2008; Roorda et al., 2011; Rucinski et al., 2018). Such an impact on teachers is particularly important for students who experience low peer status due to their deviant or aggressive behaviors in classrooms (Hendrickx et al., 2017), who receive lower support from their peers. Such student's behaviors often become maladaptive in the classrooms, hindering the development of positive relationships. While managing maladaptive behaviors in classrooms is crucial for teachers to build positive relationships with students, teachers often encounter difficulties dealing with students' maladaptive behaviors (Hodgens et al., 2000; Kasari et al., 2011; Majoko, 2016; Rotheram-Fuller et al., 2010). The difficulties are related to poor teacher well-being (Aldrup et al., 2018; Aloe et al., 2014; Corbin et al., 2019; Høglund et al., 2015). In particular, neurodevelopmental disorders, including attention deficit hyperactivity disorder (ADHD) and autism spectrum disorder (ASD), may also affect teachers' difficulties in building good relationships with their students (Ewe, 2019; Zendarski et al., 2020). They are associated with increased maladaptive behaviors in school children and central concerns in school staff. For instance, studies suggested that externalizing behaviors of children with ADHD or ASD can be primary concerns for difficulties and sources of stress (Greene et al., 2002; Zendarski et al., 2020), which negatively affects the quality of teacher–student interactions. Neurodevelopmental disorders are highly prevalent in schools, with rates ranging from 2 to 9% for ADHD (Sayal et al., 2018) and from 0.4 to 1.3% for ASD (Fombonne et al., 2021). In addition, a substantial number of students remain undiagnosed in mainstream classes (Bosch et al., 2022; Kim et al., 2011), which indicates the number could be even higher. A national survey in Japan revealed that 7.7% of elementary school students without intellectual disabilities experienced significant learning or behavioral difficulties (Ministry of Education, Culture, Sports, Science, and Technology, 2012). Therefore, understanding and managing behavior problems of students with difficulties or special needs has been required to enhance good teacher–student relationships in classrooms.

Teacher training (TT) is a program specifically designed for teachers who support students with developmental disabilities, aiming to enhance their skills in effectively engaging with these students and increasing their self-efficacy (Froelich et al., 2012; Ishii and Okuno, 2020; Ishii et al., 2020; Iwasaka et al., 2005; Onishi et al., 2015). This program draws upon a behavioral therapy program Parent training (PT) developed for parents of children with ADHD (Barkley, 2013; Whitham, 1991) and modified for Japanese parents of children with ADHD (Iwasaka et al., 2002) and ASD (Okuno et al., 2011). While parents observe their children's behavior and change interaction, teachers choose one or two students in their classes and record their behaviors to understand and help them. The teachers increase positive interactions and develop skills to deal with students' maladaptive behaviors (Onishi et al., 2015). Several studies have indicated that the teachers applied

positive attitude to the other students in the classes and lead their appropriate behaviors (e.g., helping friends who are in trouble, telling teachers about friends' good behaviors or efforts) regardless of their developmental disability (Froelich et al., 2012; Imanishi et al., 2014; Iwasaka et al., 2005; Onishi et al., 2015). Thus, TT may increase interactions between teachers and students by focusing on appropriate behavior, increasing positive feedback, and creating a supportive classroom environment; however, previous studies have exclusively utilized subjective teacher interviews (Onishi et al., 2015). Therefore, more objective measures to evaluate teacher–student interactions are required to investigate the usefulness of various educational interventions in school settings.

Conventionally, questionnaires (e.g., peer nomination) and observation have been common in evaluating interactions between teachers and students in classrooms (Pianta and Hamre, 2009; Wubbels and Brekelmans, 2005), although the methods reflect the respondents' perceptions. Another approach is coding interactive behaviors using the time sampling method by direct observations. While it is a well-known approach for assessing interactive behaviors in psychological studies, it is time-consuming and requires training. Therefore, there are challenges in using behavior observation in regular educational settings.

Recently, several studies have attempted to assess social interactions using wearable devices. Heravi et al. (2018) used bespoke wearable sensors on caps and shoes with a global navigation satellite system and inertial measurement unit to detect children interacting on a school playground. The system detected interactions based on the location of children and their linked movements and was particularly suitable for situations such as free play outside. Other studies used speech or vocal information to detect interactions between teachers and children with devices (Fasano et al., 2023; Irvin et al., 2017). Douglas et al. (2022) measured social proximity among children with ASD and their peers using sensor badges. The badges detected face-to-face interaction time and physical distance between two individuals with directional ultrasound transceivers when facing each other. Although various sensing devices have been developed, there are major challenges in detecting child behaviors and teacher–student interactions in educational settings (Elbaum et al., 2024). Wearable sociometric devices are capable of capturing and collecting data on face-to-face events between two or more individuals using infrared sensors, Bluetooth, accelerometers, and/or microphones. They enable continuous monitoring of the face-to-face interaction time of each individual and the group, whereas conventional behavioral observation measures, including direct and video observations, are time-consuming and can be affected by the quality of the recorded information, such as eye gaze, facial expressions, and gestures (Douglas et al., 2022; Yamamoto and Hanai, 2015). The device has been used in recent studies of medical communication or interactions between health professionals that provide quantified face-to-face contact among individuals (Stefanini et al., 2021; Ito-Masui et al., 2020; Kawamoto et al., 2020a; Kawamoto et al., 2020b). While wearable devices, including sociometric devices, are of interest in improving teaching and learning performance in educational settings (Khosravi et al., 2022), the available evidence of sociometric sensors in schools or children is scarce. For example, Nakajima et al. (2019, 2020) conducted wearable sociometric device measurements in physical education and reported that class communication data provide potentially useful information for

teachers, which illustrated the characteristics of communicative behaviors in the activities. Yamamoto et al. (2021) evaluated changes in the interactions of children with ASD after a group social skills intervention and showed that the devices could be useful for validating the intervention. These studies suggested some utilities of sociometric devices in evaluating children's interactions; however, further evaluations are needed to evaluate the performance of the device in detecting changes by the interventions in school settings.

This study aimed to capture changes in face-to-face interaction time during a group activity among teachers and their students, including students with special educational needs, using sociometric sensor badges before and after TT. The present study is explorative and not planned for hypothesis testing; hence, it aims to examine the nature of the sociometric device measurement by describing the measured indices, rather than a procedure to reject or support by hypothesis testing.

2 Materials and methods

2.1 Procedures

The research plan was presented to the principal, and teachers were recruited through brochures and information sessions. All participating teachers provided written informed consent. Students and their parents in mainstream classrooms of the teachers were distributed information about wearable sociometric sensor device measurement associated with intervention for the teachers through a written document. Their consent was obtained by opting out, granting them the option to refuse participation. Each participating teacher chose one or two students with special needs.

The group allocation of the study was not randomized, but was determined by the participants' intentions. Among the participating teachers, four received a TT group intervention program, and three did not receive any interventions.

We planned a group activity task to measure face-to-face time between the teachers and students. Group activities are among the most difficult situations for teachers to manage for students with behavioral problems (Faiz et al., 2019; Hirose et al., 2001). Before the measurement students were informed about the details of the activities and measurements. We evaluated face-to-face interactions between the teacher and students during a group activity using sociometric sensor devices, as well as the teacher's confidence, mental health, stress, work engagement, and efficacy. Additionally, we examined the behavioral problems of the target students of participating teachers during the TT. Interventions and measurements were conducted between September and December, 2019. This procedure was approved by the Institutional Review Board of the Graduate School of Human Sciences at Osaka University (protocol code 18056).

2.2 Participants

The participant teachers in this study were in charge of students with special needs in mainstream classrooms. The participants in this study comprised 7 elementary school teachers ($M = 36.9$,

2 men and 5 women) and 195 classroom students (101 boys and 94 girls, ranging from 6 to 12 years old) recruited from a public elementary school. The school is in a rural area of Hyogo prefecture, Japan and the school-size is medium with about 300 students. The eligible teachers for the program were (1) elementary school teachers who worked for more than 3 h a day in charge of students with special needs (e.g., difficulties in social interaction and communication, inattention, or hyperactivity), and (2) those who needed to improve their skills in dealing with students' behavior in the classroom. After teachers were recruited, students in their classrooms were recruited accordingly. The group allocation of the study was not randomized, but was determined by the participants' intentions. Among the participating teachers, four received a TT group intervention program, and three did not receive any interventions. Initially, four teachers participated in the study, but one teacher and his 37 students were excluded because the teacher's measurement was not correctly recorded during the measurement activity. Finally, 6 teachers (3 of whom received the TT intervention) and 158 elementary school students were included in the study. The characteristics of the participating teachers and students are presented in Table 1. Table 1 also shows information for 30 students with special educational needs. The special needs of students identified by the teachers included difficulties in social interaction or communication ($n = 13$, 43%), hyperactivity or inattention ($n = 7$, 23%), learning disabilities ($n = 4$, 13%), intellectual disability ($n = 1$, 3%), low vision ($n = 1$, 3%), and neurological disorder ($n = 1$, 3%). Information on other students were not available.

Written requests for cooperation in the study were submitted to the elementary school principal, and consent was obtained from all participants. All teachers provided written informed consent. Students and their parents were informed about the study through a written document and were provided opt-out consent, granting them the option to refuse participation. We also provided the students with an oral explanation before conducting the measurements. This procedure was approved by the Institutional Review Board of the Graduate School of Human Sciences at Osaka University (protocol code 18056).

2.3 TT program

The TT program comprised five group sessions, consistent with previous TT studies (Iwasaka et al., 2005; Onishi et al., 2015)—Session 1: observing and understanding the target students' behaviors; Session 2: giving positive attention to the students' behaviors; Session 3: providing clear instructions; Session 4: waiting to praise; and Session 5: setting limitations and reflections. The entire program was conducted once every 2 weeks, over 3 months. Each session was originally 90 min long, but was shortened to 60 min starting from 4 pm during the teachers' working hours. During each session, the teacher reported the good behaviors of the target students and engaged in the following activities: sharing previous practices from homework, discussing the program content, and role-playing. Additionally, the teacher was encouraged to practice the skills learned in the TT in daily teaching and to record them. The program was facilitated by a trained teacher (the first author). To ensure program fidelity, all TT sessions were video-recorded and reviewed by a supervisor (the last author) using a

TABLE 1 Participants' characteristics

Group	Class	Teacher			Class of the participating teachers				Student chosen by the participating teachers	
		Age	Sex	Experience as a teacher (years)	Grade (age)	Class size; number of students	Number of boys (%)	Number of students with special needs (%)	Number of the students	Primary problems of the students (diagnosis)
TT	a	49	Woman	14	1st grade (6–7)	23	13 (57)	3 (13)	1	Hyperactivity and inattention (No diagnosis)
TT	b	31	Woman	8	5th grade (10–11)	37	18 (49)	5 (14)	2	Aggressive behaviors (No diagnosis), Aggressive behaviors (No diagnosis)
TT	c	33	Woman	12	6th grade (11–12)	30	13 (43)	6 (20)	2	Difficulties in social interaction and communication problem (ASD), Hyperactivity and inattention (ADHD)
Control	d	32	Man	3	1st grade (6–7)	24	13 (54)	5 (21)	1	Difficulties in social interaction and communication problem (ASD)
Control	e	53	Woman	28	3rd grade (8–9)	22	13 (59)	6 (27)	1	Difficulties in social interaction and communication problem (ASD)
Control	f	24	Woman	1	3rd grade (8–9)	23	14 (61)	5 (22)	1	Difficulties in social interaction and communication problem (No diagnosis)

TT, teacher training; ASD, Autism Spectrum Disorder; ADHD, Attention Deficit Hyperactivity Disorder.

checklist (Iwasaka et al., 2012). Ten items were rated on a 10-point scale and then summed to calculate the index scores of fidelity achievement. The scores indicate an adequate fidelity to the program (82%).

2.4 Measures

2.4.1 Measurement of face-to-face interactions

The Business Microscope® (Hitachi, Ltd., Tokyo, Japan; BMS) is a wearable sociometric sensor badge that provides a quantitative index of communication in a group setting (Gouda, 2015). The BMS was equipped with an infrared sensor and accelerometer. The infrared sensor detects face-to-face events within a distance of two meters and 120-degree angle. Each device had a unique ID that provided data on the person facing the device and its duration. The accelerometer recorded the physical movements of the wearer. The badge measured 60.7 mm in length, 80.6 mm in width, and 11.5 mm in thickness, and weighed approximately 33 g. Further details of the device can be found in a technical report by Gouda (2015). We used data measured with an infrared sensor, recorded every 625 ms, during an activity task. The teachers and students wore each badge in transparent pockets in front of their bibs, as in previous studies (Nakajima et al., 2019, 2020; Yamamoto and Hanai, 2015). The total face-to-face time during the group activity task was calculated. The face-to-face interaction time was converted into time per 120 s to align the difference in measured time among the groups. We used teacher–student face-to-face time as an index of face-to-face interaction. The measurement process was video-recorded for confirmation and documentation.

In addition, we rated the teacher's behavior during the task based on video recordings as a conventional measure of teacher–student interaction time. The teacher's interactive behavior was assessed per 5-s frame during the task. Interactive behaviors such as nodding, talking, laughter, and pointing while facing or approaching the students were counted as interactions. The interaction time was converted into time per 120 s as with the BMS device measurement.

We used a group activity task to measure face-to-face time. Group activities are among the most difficult situations for teachers to manage for students with developmental disabilities (Faiz et al., 2019; Hirose et al., 2001). The students were divided into groups of five or six with the same sex ratio. Each group engaged in the block assembly task, which was planned to be completed within 15 min. The teacher was required to look after, support, and talk to students as usual.

For each group, we prepared 60 palm-sized building blocks (Kids' Adventure Jumbo Blocks, United States). The blocks were of four colors: red, blue, yellow, and green. To prevent observational learning and practice effects, the assembly tasks differed between the groups and the two time points, whereas the number of blocks required was the same. The difficulty levels of the tasks were adjusted to be similar. The rule “place the blocks next to each other so that they have different colors” was introduced to promote communication in each group. Tasks and rules were outlined at the beginning of each activity. Visual materials were also distributed so that the students in each group could review the tasks and rules. Each group was instructed to work mostly on a 2.2-m square rug.

The day of the week, time schedule, and group composition were standardized, and the students did not collaborate with the same group members between the pre and post measurement dates to avoid practice effect.

2.5 Questionnaire

2.5.1 Questionnaire on the outcomes of teacher

Confidence Degree Questionnaire (CDQ) for teachers is a teacher-report scale to score teachers' confidence in supporting students at school (Ishii et al., 2020; Iwasaka et al., 2012). The original CDQ for families was modified for teachers. The CDQ for teachers comprises 18 items and is measured with five-point scale. Participating teachers evaluated themselves with the CDQ. Higher scores indicate higher confidence.

2.5.2 Evaluations of the students selected for teacher training sessions

Teacher's Report Form of the Child Behavior Checklist (TRF) is a teacher-report scale to score students aged between 5 and 18 years (Achenbach and Rescorla, 2001). The TRF assesses the behavioral, emotional, and social problems observed in students and comprises 113 items. It is measured on a three-point scale and has eight subscales: Anxious/Depressed, Withdrawn/Depressed, Somatic complaints, Social problems, Thought problems, Attention problems, Rule-breaking behavior, and Aggressive behavior. The Anxious/Depressed, Withdrawn/Depressed, and Somatic Complaints scales loaded together on the higher order scale Internalizing, whereas the scales for Rule-Breaking Behavior and Aggressive Behavior loaded together on the higher order scale called Externalizing. The original TRF in English has been translated into Japanese and standardized in Japan (Funabiki and Murai, 2017). Participating teachers evaluated the students they chose with the TRF. Higher scores indicate the more severe problems at school.

Social Responsiveness Scale-2 (SRS-2) School-Age Form is a teacher- or parent-report scale to score children or students aged between 4 and 18 years (Constantino and Gruber, 2012). The SRS-2 identifies the presence and severity of social impairment associated with autism spectrum disorders and comprises 65 items. It is measured on a four-point scale and has five treatment subscales: Social awareness, Social cognition, Social communication, Social motivation, and Restricted interest and Repetitive behavior. Social awareness, Social cognition, Social communication, and Social motivation loaded together on Social communication and interaction on DSM-5 scales. The original SRS-2 in English has been translated into Japanese and standardized in Japan (Torii et al., 2017). Participating teachers evaluated the students they chose with the SRS-2. Higher scores indicate the more severe ASD symptoms.

2.6 Analysis

We examined whether there was a consistency in the direction of changes in teacher–student face-to-face time as measured by the device and the conventional measure (i.e., teacher behavior

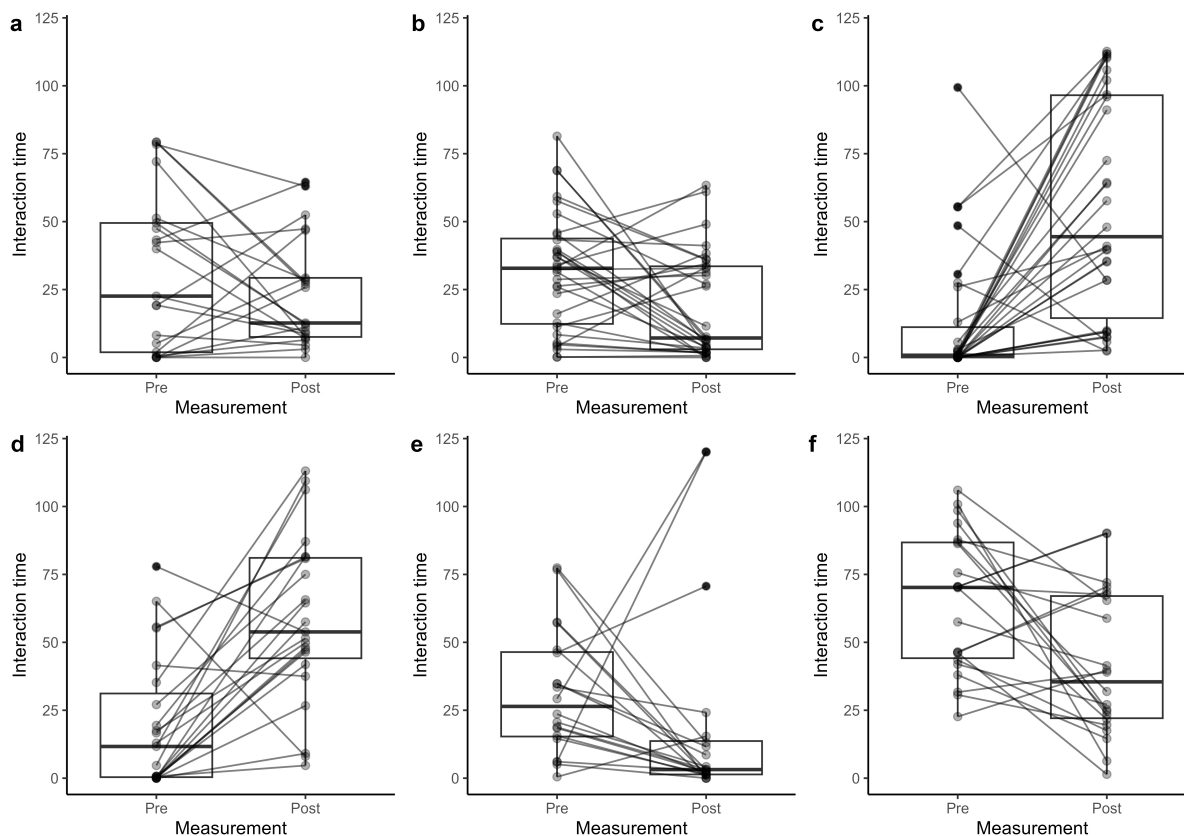


FIGURE 1 Individual pre-post changes in each student in each class. The letters indicate the classes: teachers in panels (a–c) received the TT intervention; teachers in panels (d–f) did not receive the intervention.

assessed through video rating). Because our study included only six teachers in the analysis, we did not use statistical comparisons and hypothesis testing in this analysis. We utilized network diagrams to evaluate face-to-face interactions both before and after the TT intervention. Data were transmitted to the developer’s data center and analyzed using server algorithms (Hitachi Ltd., Tokyo, Japan). Data and network diagrams were created using a visualization engine (Hitachi Ltd., Tokyo, Japan) and Cytoscape 3.8.2¹ as described in a previous report (Yamamoto et al., 2021). In the face-to-face interaction network diagram, the nodes represent each individual, and the thicknesses of the lines correspond to the total interaction time between individuals.

To explore potential intervention effects on teacher–student face-to-face time, we used a two-level mixed analysis of variance (ANOVA) to examine group differences (teacher training and control) in face-to-face time between teachers and students. In this study, pre and post measurements (Level 1) were nested within teacher–student pairs (Level 2). The teacher–student pairs were nested within the classes (Level 3). As our study had only two measurements (i.e., pre and post) for each teacher–student pair, we tried to estimate the variance of random intercepts for Levels 2 and 3. The fixed effects included time (pre and post measurement), group (teacher training and control), and their interaction term

(time × group). The treatment effects were estimated based on the coefficients of the interaction terms of the model.

The SPSS Statistics 27 (IBM Corp., Armonk, NY, USA) and R ver. 4.3.1 were used for statistical analysis. The significance threshold was set at $p < 0.05$. As our study lacking a sufficient number of classroom teachers for group comparisons, we estimated 95% confidence intervals (CI) to assess the potential effects of the interventions.

We also described the results of the questionnaires. Since the data are not adequate in sample size for hypothesis testing, we only reported individual scores for descriptive purpose.

3 Results

3.1 Face-to-face interaction time

3.1.1 Total Face-to-face interaction time between teacher and students

Individual face-to-face interaction time between teacher and students in a class measured by the sociometric device is shown in Figure 1. Video-based behavioral ratings indicated that both groups increased teacher–student interactive behaviors in one class and decreased teacher–student interactive behaviors in two classes (Table 2). In Table 2, numbers in each cell show individual teacher’s interaction time with students based on video recording ratings.

¹ <https://cytoscape.org/>

TABLE 2 Interaction time of teachers based on video recording.

Group	TT					
Class	a		b		c	
Measurement	Pre	Post	Pre	Post	Pre	Post
Count/120 s ^a	63.3	44.1	75.6	66.7	71.3	85.9
Group	Control					
Class	d		e		f	
Measurement	Pre	Post	Pre	Post	Pre	Post
Count/120 s ^a	56.7	98.7	71.5	108.7	84.0	73.2

TT, teacher training. ^aThe number in cells shows individual time during the activity for pre or post measurement.

TABLE 3 Pre and post comparisons of interaction time of teachers using the sociometric device and video recording.

Class	Directions of change (pre vs. post)	
	Business microscope	Video recording
a	–	–
b	–	–
c	+	+
d	+	+
e	–	+
f	–	–

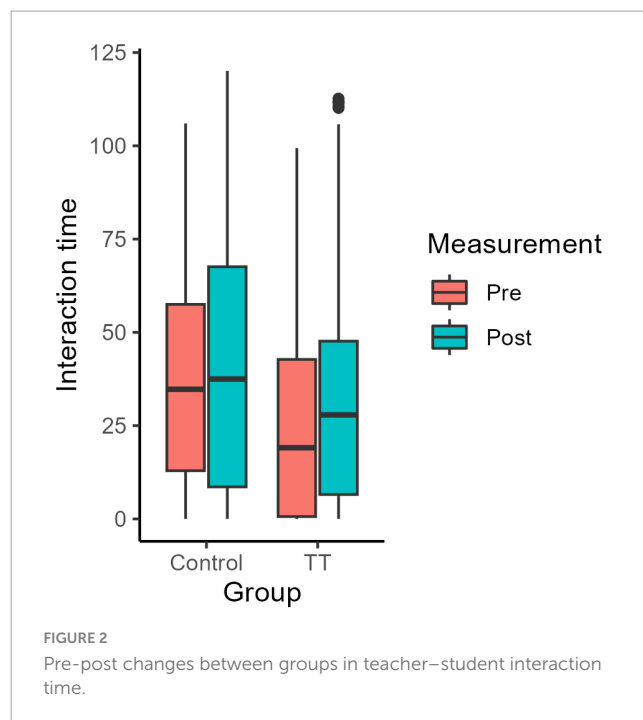
+: count of interactions increased at post measurement, -: count of interactions decreased at post measurement.

The directions of quantitative changes were consistent for five of the six teachers for the sociometric device and video rating (Table 3).

To examine potential intervention effects on teacher–student face-to-face time, we used a two-level mixed ANOVA to explore group differences (teacher training and control) in face-to-face time between teachers and students. An explorative analysis revealed that the Level 2 random intercept did not improve the model fit (Akaike Information Criterion = 2880 for the Level 2 random intercept model and 2875 for the Level 3 random intercept model). Consequently, only the Level 3 random intercept was estimated in the following analysis. The statistical analyses did not show a significant difference in face-to-face interaction time between the TT and control groups ($b = 3.94$, $SE = 7.09$, $95\% \text{ CI} = [-9.95, 17.82]$). Figure 2 illustrates the pre-post changes in interaction time between the teacher and students, revealing no clear trends toward an increase or decrease between the TT and control groups. The face-to-face interaction network diagrams depict the total face-to-face time for every student pre- and post-TT (Supplementary Figures 1, 2).

3.2 Questionnaires

The results for individual teachers are shown in Supplementary Tables 1, 2. There were no clear improvements in teachers’ mental health, confidence, work engagement, and self-efficacy.



Supplementary Table 3 presents the TRF and SRS scores of the students selected by the teachers.

4 Discussion

In this study, we used wearable sociometric sensor devices to capture changes in teacher–student face-to-face interactions following TT. The device detected variability of pre-post changes between the teacher and students during a group activity task. These changes in the measurements were consistent in five of the six teachers, aligning with those obtained via conventional measurement—video-based behavioral ratings of interactive behaviors—thus supporting the validity of these devices in measuring teacher–student face-to-face interactions. In one class (class e), there was a discrepancy in the direction of change in interaction with the teacher before and after TT in the video recordings and sociometric devices (Table 3). This class showed an increase in interaction patterns that were biased toward one group at the post-measurement, which was different from the other classes (Supplementary Figures 1, 2). The consequence of the pattern was an increase in teacher interaction behavior, but a decrease in interaction with the children in the class as a whole. In addition, there were disparities in the ranges of interaction time measured by the sociometric device and teacher behavior ratings (Figure 1 and Table 2). While the sociometric device captured the face-to-face time with individual students, the behavior ratings index only reflected the teacher’s behavior itself. The wearable sociometric device measures a different component of the teacher–student interaction. This variance in index characteristics results in a discrepancy in the range of measured interaction times. Wearable sociometric devices offer objective measures to capture interaction changes through classroom interventions, which have not been evaluated by teacher behavior ratings. Another possible explanation

may be the questionable reliability of the device in measuring face-to-face interactions. As suggested by [Hodge et al. \(2020\)](#) the use of sociometric devices has not been well-validated in children. They also suggested that cautious evaluations are required for use of sociometric devices in measuring communication data. This study added partial evidence for measurement validity of the sociometric device in an elementary school setting, although further refinement would be necessary.

Measuring face-to-face time with more than one child requires multiple observers and video recordings, and the time required depends on the number of groups and group size ([Yamamoto and Hanai, 2015](#)). In this study, only teacher interactions could be counted in the videotaped data, and it was not possible to identify all child interactions. While video recording requires that the activity take place within the screen's confines, sociometric devices do not limit the location of activities. Thus, the sociometric devices provide better utility in measuring activities between multiple teachers and children in schools, as suggested in this study. The sociometric devices make it possible to measure face-to-face information easily and over time. In addition, the time required to analyze face-to-face measures can be greatly reduced by reducing the need for manual coding ([Yamamoto and Hanai, 2015](#)). Even when observer masking is required for interventional studies, such tools facilitate objective evaluations. With these advantages, the tool may be helpful in measuring the educational benefits of school or classroom interventions by incorporating frequent, repeated measurements in everyday life in studies. However, we cannot identify what kind of interaction occurred in a face-to-face encounter with the tool alone, i.e., positive or negative interactions ([Yamamoto et al., 2021](#)). Therefore, multimodal measurements, such as location, movement synchronization, and speech synchronization (e.g., [Lederman et al., 2018](#)), may be considered in conjunction when specifying such detailed meanings is critical.

We did not identify any significant changes due to the TT intervention, although the variance in the outcome was partially explained by differences among individual teachers (Level 3). The results should be interpreted with caution because our sample comprised only six teachers. Because of the small number of teachers, individual differences among teachers, such as years of teaching experience and knowledge about child behavior problems, may affect the current results. In addition to the teacher's characteristics, the classroom composition would also be a critical factor that affects the potential impact of the intervention ([Aguiar and Aguiar, 2020](#)). In future interventional studies, such information is also required to understand the potential and interfering effects of educational interventions. Additionally, an increase or decrease in face-to-face interaction time during an activity may not correspond to positive behaviors or changes in teachers. Changes in indices themselves do not define the meaning of their behavior in a particular context. A TT intervention may either increase or decrease teachers' interactions depending on their functions (i.e., positive or negative). Therefore, changes in interaction time must be accompanied by meaningful indices or assessments of the functions of teachers' behaviors to interpret their functions. It should be noted that overly focusing on changes in such indices may instead hinder teachers from improving their behavior ([Ito et al., 2020](#)). Moreover, the measurements were conducted shortly after the program, and the time span may not

have been adequate to observe behavioral changes in both teachers and students.

4.1 Strengths and limitations

The strength of this study was that it examined face-to-face interactions with a larger sample size of elementary school students. This study suggested that changes in face-to-face interactions can be measured using the Business microscope in classroom activities and the merits of further validation of the sociometric devices in school settings. Such new devices and technologies would provide us with a better balance between effort and accuracy of the data measurement. Further validations of such techniques facilitate the progress of research in educational practices.

This study had several limitations. It should be noted that the present study was explorative to describe the characteristics of the sociometric device. Therefore, our study did not use hypothesis testing to validate the measurement due to the method used and sample size issues, except for the TT group comparisons. These limitations may limit the credibility of the findings of this study. In future studies, measurement characteristics should be established by studies with more rigorous methods with pre-registration and hypothesis testing or multimodal and extensive measurements in classrooms. Second, the results are based on a limited sample size. Results obtained from a larger number of teachers would facilitate a meaningful interpretation of interactions at each level (students and teachers). While this is an exploratory study, the participants were recruited from only a single school setting. These study characteristics may limit the findings' generalizability to diverse educational contexts (e.g., geographical settings, educational systems, and countries). The characteristics of the children or teachers may affect the reliability of the measurements. Third, face-to-face measurements between the teacher and students were conducted in experimental situations using group activities. The nature of the activities may affect teachers' behaviors, thereby influencing communication among teachers and students. The teacher-student interaction in this study was measured in a group activity that required student-student interaction using blocks to maintain an even distance between the groups. This setting had the property of equalizing the initial distance between the teacher and each student and enhancing the opportunity for interaction with each individual. However, this was a different form of interactive situation from the in-class activities in the classroom setting. It should be noted that the nature of the interaction may be different from the nature of interaction in a classroom setting. In future studies, it may also be useful to examine differences in measurement in natural settings and structured activities. Fourth, the interpretation of the index is affected by the context. The current study collected solely face-to-face interaction time without qualitative information on the nature of these interactions (e.g., positive or negative, instructional, or corrective). Future studies should include measurements that contain cues determining the nature of these interactions, allowing for more meaningful interpretations. Furthermore, developing sociometric devices that enable the combining of multimodal information and processing of the nature of the interactions between individuals may be beneficial for future studies. While the privacy of the

teachers and students should be strictly protected (Kumar et al., 2019; Ogan, 2019), such an approach would provide implications for future educational practice.

5 Conclusion

Our study suggests that wearable sociometric sensor devices can capture changes in teacher–student face-to-face interactions in the classroom. Therefore, assessing group interactions using wearable sociometric devices is a promising method for evaluating changes in interactions through school interventions.

Data availability statement

The datasets presented in this article are not readily available because the data for the current study was not available due to ethical restrictions. Requests to access the datasets should be directed to HF, fjinoh@kokoro.med.osaka-u.ac.

Ethics statement

The studies involving humans were approved by Institutional Review Board of the Graduate School of Human Sciences, Osaka University. The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because Students and their parents were informed about the study through a written document and were provided opt-out consent, granting them the option to refuse participation. We also provided the students with an oral explanation before conducting the measurements.

Author contributions

TN: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Visualization, Writing – original draft, Writing – review and editing. HF: Conceptualization, Formal Analysis, Project administration, Supervision, Visualization, Writing – original draft, Writing – review and editing. TY: Investigation, Writing – review and editing. AI: Data curation, Writing – review and editing. MT: Conceptualization, Funding acquisition, Supervision, Writing – review and editing. HO: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Generative AI was used in the creation of this manuscript.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feduc.2025.1545758/full#supplementary-material>

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