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ORIGINAL PAPER

Supporting Social Skills in Autism Through Motion-Based Gaming Technology: A Feasibility Study

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Abstract

Purpose This study evaluated the feasibility and effectiveness of a motion-based gaming intervention designed to enhance social skills in individuals with autism spectrum disorders (ASD).

Methods Twenty-eight participants with ASD took part in 10 sessions (5 weeks), engaging in cooperative virtual games. Each session required coordination with a partner. Half of the participants (PEER group) collaborated with a peer, while the other half (EDU group) worked with a therapist. Neuropsychological and behavioral measures were collected at baseline (T0), post-intervention (T2), and after 3-month (T3).

Results Both groups showed improvements in Theory of Mind, which were maintained at T3. Notably, the EDU group also demonstrated significant gains in Memory for Faces, possibly due to therapists' focus on facial engagement. Motion-based gaming, especially when supported by educators, appears effective in improving social and cognitive skills in people with ASD. Limitations (i.e., the absence of a control group and test sensitivity) warrant consideration in future research.

Keywords Autism spectrum disorder (ASD) · Motion-based technology · Social skills · Peer-mediated intervention

Beside repetitive behaviors and atypical sensory processing, a core symptom of autism spectrum disorder (ASD) is a profound difficulty with social communication and interaction (American Psychiatric Association, 2000). An extensive body of research confirms that children with ASD face significant challenges in engaging in appropriate social interactions, particularly with peers (Bauminger-Zviely, 2013; Grossman et al., 1997). Unfortunately, these challenges often intensify with age, becoming a primary concern for adolescents and adults with ASD. This can be driven by a greater awareness of social dynamics and an accumulation of negative social experiences (Corbett et al., 2010), leading to an increasing sense of social isolation that often characterizes late adolescence and early adulthood (Schiltz et al., 2024). Of note, these difficulties affect individuals on the autism spectrum regardless of their level of cognitive ability. Even among individuals with ASD who present relatively preserved cognitive skills, cognitive competence does not necessarily translate into appropriate social behavior, and difficulties in establishing relationships often remain more pronounced than in typically developing peers (Bauminger et al., 2003; Sipowicz et al., 2023).

Notably, research has shown that the way we physically interact with our environment significantly impacts how we learn and engage with others, starting from a very early age (Clearfield, 2011; Clearfield et al., 2008; Karasik et al., 2011). A substantial body of studies has confirmed the presence of motor atypicalities in up to 80% of children with ASD (Ruggeri et al., 2020), and motor proficiency in toddlers with ASD has been shown to significantly predict the development of communication skills (MacDonald et al., 2013). These findings have contributed to a growing

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theoretical framework suggesting that motor development, social interaction, and communication are deeply interconnected processes (Wang et al., 2022). Consistently, many authors have suggested that early interventions targeting sensorimotor skills could positively influence social learning in children with ASD (Bremer et al., 2016) and mitigate social difficulties in older individuals (Keller et al., 2022).

Motion-based gaming technology has recently emerged as a particularly promising tool for supporting learning within a highly motivating and engaging context (Ben-Zeev, 2014). To date, most motion-based gaming interventions have focused on populations with dementia (Dove et al., 2020; Eisapour et al., 2020), stroke (see Mubin et al., 2022), or cerebral palsy (Weiss et al., 2014; Stansfield et al., 2015) and have primarily targeted physical rehabilitation outcomes. However, a growing body of evidence indicates that these technologies may also hold significant potential for social skill development, especially when they involve interaction between multiple players. Collaborative gaming, specifically involving coordinated activity between two individuals, has been shown to enhance both adherence to and effectiveness of motor-based interventions (Peng et al., 2013; Portnoy et al., 2017; Pereira et al., 2021), thereby highlighting an important social dimension of these approaches. On the one hand, active video games may encourage individuals to refine their motor actions in order to successfully engage with a social partner, thus supporting motor skill development. For example, Portnoy et al. (2017) showed that children with developmental coordination disorder (DCD) who played motion-based games with a partner exhibited greater improvements in balance control compared to solo play, alongside increased motivation arising from peer engagement. On the other hand, through full-body, real-time interaction, motion-based games may indirectly promote interpersonal coordination and joint action, which can be considered foundational prerequisites for social abilities. The capacity to voluntarily synchronize one's movements with others has been shown to be reduced in individuals with ASD and is also associated with social competence (Fitzpatrick et al., 2016, 2018). Consistently, typically developing individuals with elevated autistic traits in the domains of social skills and communication also display reduced motor synchrony abilities (Chen et al., 2023), further supporting a link between interpersonal motor coordination and social functioning. Taken together, these findings suggest that interventions explicitly designed to promote coordinated motor interaction may represent a promising avenue for supporting social skill development in individuals on the autism spectrum.

In this exploratory study, we designed a motion-based gaming training to support the social skills of adolescents and adults on the spectrum with varying levels of support needs. We required participants to coordinate in space and time with a partner to complete a series of virtual games. Participants were paired with either an educator or another autistic individual with comparable support needs. Our primary aim was to test whether a kinematic virtual environment could be effective in promoting social competence by engaging participants in dual-player motor activities. A secondary aim was to explore the differential impact of the partner relationship. The literature has shown peer-mediated interventions to be a promising tool for improving social interaction and the opportunity to generalize social learning to different contexts (Watkins et al., 2015). Grounded in these premises, we hypothesized that the paired intervention would enhance social abilities and that the peer-based condition would prove most effective.

Methods

Participants

A total of 29 adolescents (females = 6) and young adults with ASD, aged 11–27 years (mean = 17.11, SD = 4.51), were recruited at the Fondazione Progettoautismo FVG Onlus in Feletto Umberto (Udine), a center for occupational and educational activities. Eligibility criteria included a formal ASD diagnosis and regular attendance at the center (at least twice per week), ensuring familiarity with structured group activities and sufficient tolerance for a novel training context. Following a presentation of the study's aims and procedures, informed consent was acquired from the families; adults who were not under legal guardianship provided written informed consent themselves, after their parents or caregivers had been fully informed about the study procedures.

During screening, one participant was excluded due to severe behavioral problems that could compromise the reliability of neuropsychological tests. The final 28 participants were enrolled and divided into two groups: the EDU group ($n = 14$; females = 4; mean age = 16.43, SD = 3.88), composed of 14 peer-educator couples, and the PEER group ($n = 14$; females = 2; mean age = 17.78, SD = 5.12), composed of 7 couples of autistic peers with comparable support needs. Educators involved in the intervention were licensed professionals (either professional educators or psychologists) employed at the hosting center. All educators were familiar with the participants, having previously worked with them in educational, laboratory-based, or therapeutic activities. This prior relationship allowed educators to adapt their interaction style to participants' individual needs while ensuring continuity with ongoing support practices. An educator was also present to supervise the PEER group sessions but was instructed not to intervene in the activity.

All participants had a previous diagnosis of autism according to DSM-IV (APA, 2000) or ICD-10 (WHO, 1993)

Table 1 Demographic statistics, IQ, and level of autism of the participants

Peer group					Edu group				
Name	**Sex**	**Age**	**IQ**	**Level**	**Name**	**Sex**	**Age**	**IQ**	**Level**
MS	M	18	94	2	**CD**	F	18	110	3
MV	M	21	120	3	**DM**	M	11	105	2
GD	M	22	108	3	**AP**	M	16	128	1
SC	F	16	92	3	**JT**	M	12	75	2
DO	M	16	73	2	**SN**	F	15	60	2
PG	M	25	60	2	**CP**	F	24	114	1
AC	M	20	117	1	**GC**	M	15	65	3
DE	M	27	117	1	**RP**	M	11	72	2
ED	F	11	125	1	**AB**	M	24	60	3
AF	M	18	74	2	**MC**	M	15	104	1
AM	M	11	82	1	**SS**	M	18	60	3
LL	M	18	84	3	**ER**	M	16	94	3
GI	M	12	110	1	**SP**	F	16	127	1
GO	M	12	120	1	**SM**	M	18	62	3

IQ intelligence quotient, *Level* level of autism

criteria. Based on clinical evaluation, participants were classified according to DSM-5 levels of support needs, with ten individuals requiring level 1 support, eight requiring level 2 support, and ten requiring level 3 support (Table 1). These levels refer to the amount of support required in daily functioning and do not represent fixed or global measures of individual ability. All participants but one were verbal. The procedures were approved by the local ethics committee (Commissione di Garanzia per il Rispetto dei Principi Etici Nell'attività di Ricerca Sugli Esseri Umani, Department of Languages and Literatures, Communication, Education and Society, University of Udine) and conformed with the Declaration of Helsinki (1975).

Training Setting

The habilitation trainings were administered in the multisensory room at the Fondazione Progettoautismo FVG Onlus, using the Timocco platform (https://www.timocco.com). Timocco is an online platform with over 50 therapeutic games for motor and cognitive disabilities, featuring training plans that can be tailored to each player's specific needs and goals.

The virtual motion-based technology tracks a person's movements through a webcam. Players wear a colored, spherical-shaped glove (red, green, or blue), and the webcam identifies their movement via color contrast, with a maximum of two colors tracked simultaneously (e.g., two participants each wearing one glove). Before starting, the program requires calibration to identify the sensor(s). Players then stand 1–1.5 m from the camera to play.

During the training, the computer screen was projected onto the wall. A small video window at the bottom allowed players to self-monitor their movements by showing their image within the game environment. A researcher monitored participant performance from a computer in an adjoining room. The entire setting required a computer, a webcam, a kinect, and a projector.

Design

The experimental design was configured as an interventional study. Twenty-one pairs of participants, who remained stable throughout the sessions, completed the entire training. Before starting the intervention (T0), a pre-training evaluation was administered to all participants. It consisted of two or three meeting, lasting one hour each, in which participants completed (i) a battery of selected neuropsychological tests from the Developmental NEuroPSYchological Assessment, 2nd edition (NEPSY-II; Korkman, 2007); (ii) the Raven's progressive matrices (Raven, 1936); and (iii) the Children's Quality Of Life questionnaire (TACQOL; Vogels et al., 1999). Once the evaluation was completed, the VR training was scheduled and the plan was communicated to the participants and their parents, to ensure adherence to the training. The training was structured into 10 sessions of 60 min each, held twice a week for five weeks. Due to COVID-19 restrictions, three couples were required to pause the training, two for one week and one for two weeks, resulting in the completion of the sessions over a 6- or 7-week period. Immediately after completing the training (T2), each participant took part again in two or three sessions of individual neuropsychological assessment, where the same neuropsychological tests from NEPSY were proposed. Lastly, after 3 months (T3), all participants took part for the third time to the neuropsychological assessment, where the TACQOL

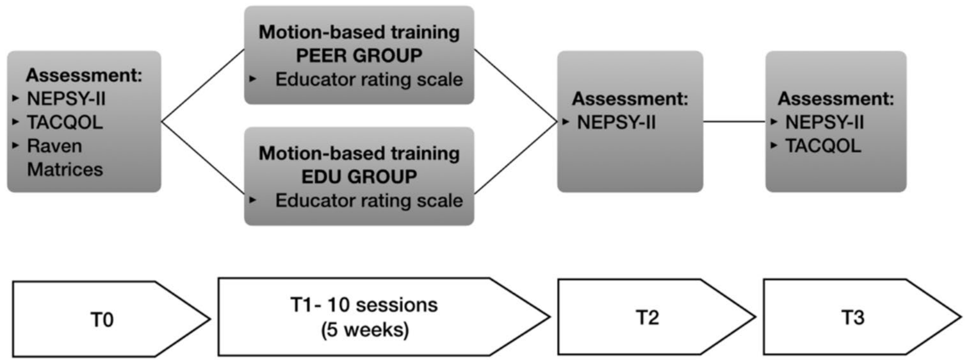

Fig. 1 Schematic representation of the timeline of the experiment. At the baseline (T0), neuropsychological, quality-of-life, and IQ tests were administered. Then, the training phase started (T1). Soon after completing the training, the neuropsychological assessment was proposed again (T2). After 3 months, neuropsychological and quality-of-life assessments were administered for the last time

were completed for the second time by participants and their parents (Fig. 1). The experimenter (a psychologist), who was not blinded to the group assignment, administered all the neuropsychological tests (at T0, T2, and T3), the TACQOL questionnaires (T0 and T3), and the Raven Matrices (T0). Furthermore, the experimenter directed the activities, all through the sessions, for each couple of participants.

Despite the challenges and restrictions imposed by the COVID-19 pandemic, we were able to adapt our procedures (e.g., by using face masks) and successfully complete the research, ensuring compliance with safety protocols while maintaining the integrity of the study.

Timocco Training

Training sessions were scheduled in order to accommodate one couple at a time, twice a week. Before starting each session, the experimenter welcomed the participants and let them explore the room for a few minutes. Participants were asked to reach agreement on the choice of the controllers (red, blue, or green). Then, the projector was switched on while the room lights were turned off, so the participants understood that the activity was about to start. Each session was composed of 4 teamwork games, selected from the list of available games (see Supplementary materials) by the experimenter. Games could be performed as turn-taking activities or cooperative activities. The first ones refer to activities in which participants alternate actions or responses, allowing each player a chance to contribute sequentially; in these games, participants could often be physically separated, although they had to coordinate with one another. The second ones involve 2 players working together, often working closely and sometimes even with their hands joined. All participants were exposed equally to both kinds of activities. The duration and the difficulty of games could vary among couples, depending on the behavioral activation of participants and their cognitive and attentional abilities. In general, games were organized and set up in order to progressively increase the complexity of the activity, both within the session (from game 1 to game 4) and across sessions (from session 1 to session 10). In each session, after completing 2 games, participants could have a brief break. In the end, participants had ten minutes of relaxation inside the room, without any video, sound, or music.

Neuropsychological and Behavioral Measures

As mentioned, the neuropsychological evaluation was conducted at each stage of the study using the Italian version of the NEPSY-II, a widely used test battery for children and adolescents (Butti et al., 2024; Ferrari et al., 2022; Narzisi et al., 2013). We administered 7 subtests to assess different domains: Theory of Mind (ToM) and Emotion Recognition (ER) for social abilities; Memory for Faces (MF) for mnemonic skills; Imitating Hand Position (IP) and Manual Motor Sequences (MMS) for motor abilities; Geometric Puzzles (GP) for visuospatial abilities; and Inhibition (I) for executive functions. Raw scores were transformed into scaled scores (mean = 10, SD = 3) according to normative tables (Urgesi et al., 2011), and a composite score was calculated for subtests yielding multiple outcomes.

To measure health status, we administered the 56-item TNO AZL Child Quality Of Life (TACQOL) in both self- and parent-compiled versions. The test provides 5 parameters: BODY, MOTOR, AUTO (Autonomy), COGNIT (cognition), and SOCIAL. It also includes two scales for general mood: EMOPOS (Positive emotions) and EMONEG (Negative emotions).

The Raven Matrices were administered to measure non-verbal IQ and abstract reasoning skills as inclusion criteria.

To assess individual changes throughout the training, an ad-hoc "Educator rating scale" (see Supplementary materials) was completed by the educator after each game session. The educator (partner in the EDU group or supervisor in the PEER group) rated the participant's performance on a 5-point Likert scale on five parameters: attention skills, communication abilities, relationship, comprehension, and tolerance to sensory stimulation. Due to technical issues, data were collected for only nineteen of the twenty-eight

Table 2 Descriptive statistics for all the measures considered in the study

	T0		T2		T3	
	Peer	Edu	Peer	Edu	Peer	Edu
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
TOM	−0.72 (12.03)	−9.59 (16.20)	2.54 (9.02)	−5.58 (12.99)	0.05 (12.32)	−5.67 (14.46)
ER	4.05 (7.17)	−1.23 (10.81)	5.18 (6.09)	0.74 (9.80)	4.92 (5.64)	1.57 (7.04)
GP	5.37 (4.67)	3.03 (7.27)	6.52 (4.52)	3.69 (8.00)	7.95 (4.98)	4.74 (8.55)
MF	6.34 (5.28)	4.50 (5.98)	5.39 (6.35)	6.94 (4.33)	8.37 (4.80)	6.99 (4.85)
IP	5.07 (7.15)	0.53 (13.65)	7.48 (6.61)	1.44 (13.85)	8.09 (5.64)	3.25 (14.10)
SMM	6.20 (5.30)	2.63 (7.91)	6.37 (5.49)	2.73 (7.68)	7.15 (4.34)	3.88 (7.22)

M mean, *SD* standard deviation, *TOM* Theory of the Mind, *ER* Emotion Recognition, *GP* Geometric Puzzles, *MF* Memory for Faces, *IP* Imitating Hand Positions, *MMS* Manual Motor Sequences

participants, so these analyses were conducted without comparing PEER and EDU groups.

Finally, to assess feasibility, we collected the number of dropouts and the number of sessions completed by each participant.

Results

All analyses were conducted in R (R Core Team, 2024). Before conducting the statistical analysis, the demographic, clinical, and neuropsychological variables of the two groups of participants were inspected through descriptive statistics.

We first assessed whether the intervention influenced NEPSY-II outcomes, comparing the improvements from T0 to T1 and T2, while also considering the differences between the groups (i.e., the PEER and EDU groups). Descriptive statistics of NEPSY-II measures are reported in Table 2. Missing values were treated with listwise deletion (i.e., one participant did not complete the SMM evaluation at the pretest assessment).

To assess whether the two groups (i.e., PEER and EDU) were comparable at the baseline, we conducted independent sample t-tests. They revealed that, at the T0, participants did not statistically significantly differ in any subtests [ToM, $t(23.995) = -1.643$, $p = 0.113$; ER, $t(22.576) = -1.523$, $p = 0.142$; GP, $t(22.149) = -1.012$, $p = 0.322$; MF, $t(25.602) = -0.860$, $p = 0.398$; IP, $t(19.629) = -1.101$, $p = 0.284$; and MMS, $t(20.754) = -1.365$, $p = 0.18$].

To evaluate both the score change from T0 to T2 and T3 and group difference following the intervention, we specified for each assessment a linear mixed model. Specifically, for each model, we set each measure as dependent variable and as fixed predictors we set Time (i.e., T0, T2, and T3), Group (i.e., EDU and PEER) and the interaction Time × Group. Participants were set as random intercept. The mixed regression model equation is shown below (see Eq. 1).

$$Y_{ij} = \beta_0 + \beta_1(Time)_j + \beta_2(Group)_i + \beta_3(Time \times Group)_{ij} + \mu_i + e_{ij} \quad (1)$$

Y_{ij} represents the score of the dependent variable for the participant i at Time j. β_0 is the fixed intercept that represent the average score at pretest in the reference group (peer). $\beta_1(Time)_j$ is the coefficient of the main Time effect, reflecting the average change over time, controlling for Group. $\beta_2(Group)_i$ is the coefficient associated with the Group, that represent the average difference between groups (i.e., educational vs. peer), controlling for Time. $\beta_3(Time \times Group)_{ij}$ is the interaction between Time and Group, indicating whether the score changes in Time differs by Group. μ_i is the random intercept for each participant i account for the individuals' variability at pretest. Finally, e_{ij} indicates the residual that is the error not explained by the model for each observation.

The Interclass Correlation (ICC) at the participants' level is reported for each model in Table 3.

The linear mixed model results indicate different interventional patterns depending on the dependent variable examined. Considering ToM, both Time factors (T2 and T3) show statistically significant effects, indicating that the reference group (EDU) improves statistically significantly at both T2 and T3 compared to the T0. In contrast, the interactions between Time and Group (PEER) are not statistically significant, suggesting that the changes over time do not differ significantly between the two groups. For ER and SMM, neither $Time_{T2}$ nor $Time_{T3}$ yields a significant effect, indicating that the EDU group does not exhibit statistically significant changes from T0 to either T2 or T3. In addition, the Time × Group (PEER) interactions are not significant, suggesting no significant differences in the improvements of the two groups over time. For GP and IP, only $Time_{T3}$ is statistically significant, indicating improvement in the EDU group from T0 to T3. No significant Time × Group (PEER) interactions emerge, suggesting that both groups follow a similar trajectory over time. Finally, results for MF show significant positive effects for both Time factors, indicating that the EDU group improves significantly from T0 to both

Table 3 Linear mixed effect models for each dependent variable

		Estimate	SE	*df*	*t*-value	*p*-value	ICC
TOM							0.896
	Intercept	−9.588	3.481	29.92	−2.754	0.010*	
	$Time_{posttest}$	4.005	1.584	52.00	2.528	0.014*	
	$Time_{follow\text{-}up}$	3.917	1.584	52.00	2.473	0.017*	
	Group[a]	8.864	4.923	29.92	1.800	0.082	
	$Time_{posttest}$ * Group[a]	−0.741	2.240	52.00	−0.331	0.742	
	$Time_{follow\text{-}up}$ * Group[a]	−3.147	2.240	52.00	−1.405	0.166	
ER							0.739
	Intercept	−1.234	2.135	37.26	−0.578	0.567	
	$Time_{posttest}$	1.978	1.541	52.00	1.284	0.205	
	$Time_{follow\text{-}up}$	2.805	1.541	52.00	1.820	0.074	
	Group[a]	5.281	3.020	37.26	1.749	0.088	
	$Time_{posttest}$ * Group[a]	−0.843	2.180	52.00	−0.387	0.700	
	$Time_{follow\text{-}up}$ * Group[a]	−1.935	2.180	52.00	−0.888	0.379	
GP							0.893
	Intercept	3.027	17.492	30.05	1.731	0.094	
	$Time_{posttest}$	0.664	0.8082	52.00	0.822	0.415	
	$Time_{follow\text{-}up}$	1.710	0.8082	52.00	2.115	0.039*	
	Group[a]	2.339	24.738	30.05	0.945	0.352	
	$Time_{posttest}$ * Group[a]	0.494	11.430	52.00	0.432	0.667	
	$Time_{follow\text{-}up}$ * Group[a]	0.876	11.430	52.00	0.766	0.447	
MF							0.737
	Intercept	4.503	1.420	37.36	3.171	0.003**	
	$Time_{posttest}$	2.435	1.029	52.00	2.367	0.022*	
	$Time_{follow\text{-}up}$	2.486	1.029	52.00	2.416	0.019*	
	Group[a]	1.833	2.008	37.36	0.913	0.367	
	$Time_{post}$ * Group[a]	−3.378	1.455	52.00	−2.322	0.024*	
	$Time_{follow\text{-}up}$ * Group[a]	−0.457	1.455	52.00	−0.314	0.755	
IP							0.943
	Intercept	0.532	2.894	28.06	0.184	0.855	
	$Time_{posttest}$	0.907	0.975	52.00	0.930	0.357	
	$Time_{follow\text{-}up}$	2.720	0.975	52.00	2.789	0.007**	
	Group[a]	4.534	4.093	28.06	1.108	0.277	
	$Time_{posttest}$ * Group[a]	1.511	1.379	52.00	1.096	0.278	
	$Time_{follow\text{-}up}$ * Group[a]	0.302	1.379	52.00	0.219	0.827	
MMS							0.817
	Intercept	2.251	1.739	34.52	1.295	0.204	
	$Time_{posttest}$	0.484	1.069	51.19	0.453	0.653	
	$Time_{follow\text{-}up}$	1.628	1.069	51.19	1.523	0.134	
	Group[a]	3.947	2.446	33.92	1.613	0.116	
	$Time_{posttest}$ * Group[a]	−0.308	1.492	51.10	−0.206	0.837	
	$Time_{follow\text{-}up}$ * Group[a]	−0.675	1.492	51.10	−0.452	0.653	

T2 and T3. Unlike the other variables, there is a significant interaction between $Time_{T2}$ and Group (PEER). This negative interaction effect suggests that while the EDU group shows an improvement from T0 to T2, the PEER group's improvement during this interval is smaller. The absence of a significant interaction at T3 indicates that, in the long run, the difference in improvements between the two groups is no longer evident (see Fig. 2). In summary, the Time factor appears to be significant for TOM, GP, MF, and IP, but with distinct patterns. Time × Group interactions are generally not significant, except for MF, where the PEER group's improvement from T0 to T2 is less pronounced compared to the EDU group. For ER and MMS, no significant changes or group differences emerge over time.

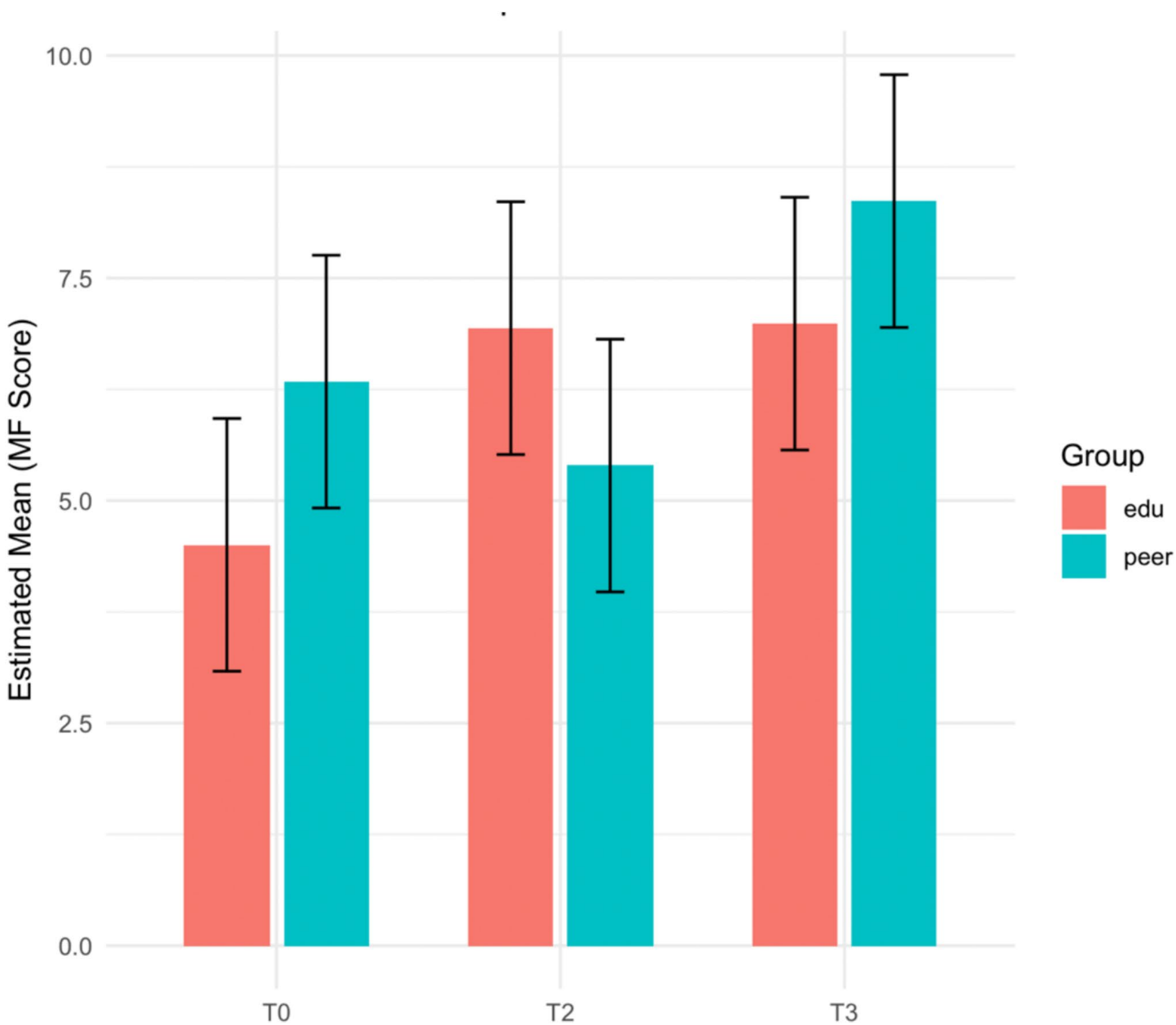

Fig. 2 The graph represents the results for MF. While the EDU group shows an improvement from T0 to T2, the PEER group's improvement during this interval is smaller. At T3, the difference in improvements between the two groups is no longer evident

As concerns the TACQOL, to evaluate the differences between the two groups, we conducted Wilcoxon rank-sum test (Wilcoxon, 1945) independent *t*-tests on the gains produced by participants, i.e., the arithmetic differences between T2 and T0 (follow-up effect delta), with higher values corresponding to stronger improvements from the T0 assessment. Wilcoxon's rank-sum test was employed to ensure robustness against potential violations of normality assumptions. No significant differences emerged in the scores reported in either the self-reported (EDU group: all $ps > 0.22$; PEER group: all $ps > 0.24$) or parent-reported (EDU group: all $ps > 0.56$; PEER group: all $ps > 0.68$) modules between T0 and T3, suggesting that neither the peers nor the educator intervention had a visible impact on the quality of life after 3 months.

Longitudinal Monitoring

To evaluate changes in educators' perceptions over time (longitudinal monitoring), we employed a multilevel model using an ad hoc developed instrument (i.e., *Educator Rating Scale*; see Supplementary materials). In this model, the dependent variable consisted of the educators' ratings on the subscales, recorded at each training session. The

Table 4 Mixed linear model results: observed changes through sessions

		Estimate	SE	*df*	*t*-value	*p*-value	ICC
Attention skills							0.467
	Intercept	3.794	0.157	33.537	24.19	$<0.001^{***}$	
	Session	0.051	0.015	170	3.40	$<0.001^{***}$	
Communication skills							0.229
	Intercept	3.082	0.166	61.070	18.562	$<0.001^{***}$	
	Session	0.050	0.021	170	2.378	0.018^{*}	
Relationship							0.306
	Intercept	3.594	0.154	48.373	23.278	$<0.001^{***}$	
	Session	0.066	0.018	170	3.715	$<0.001^{***}$	
Comprehension							0.449
	Intercept	3.967	0.170	34.718	23.326	$<0.001^{***}$	
	Session	0.052	0.016	170	3.202	0.002^{**}	
Tolerance to sensory stimulation							0.338
	Intercept	3.629	0.112	44.459	32.385	$<0.001^{***}$	
	Session	0.068	0.012	170	5.477	$<0.001^{***}$	

SE standard error, *df* degrees of freedom, *t-value* t-test statistic, *ICC* interclass correlation

$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

independent variable was the training session (Session), treated as a fixed effect, while the participant was included as a random intercept. This hierarchical structure allows us to assess both within- and between-participants rating over time. Specifically, considering the multilevel regression model equation (see Eq. 2), Y_{ij} represent the rating given by the educator j ratings at the session i. β_0 is the fixed intercept, representing the average baseline score at Session 0. β_1 is the Session coefficient, indicating the average scores' change across sessions. μ_{0i} represent the random intercept effect for each participant j, assessing individual deviations from the baseline. Finally, e_{ij} is the residual error associated with session i for participant j. The results (see Table 4) indicated that the scores reported by educators on the ad hoc-developed questionnaire, namely attention skills, communication skills, relationship, comprehension, tolerance to sensory stimulation), showed a statistically significant positive increase over the course of the intervention sessions.

$$Y_{ij} = \beta_0 + \beta_1(Session)_{ij} + \mu_{0i} + e_{ij} \tag{2}$$

Discussion

This study examined the effect of a motion-based intervention on the social abilities of young adults with ASD, comparing two conditions: an educator-mediated training and a peer-mediated training. Following a 10-session intervention, both groups demonstrated significant and comparable improvements in Theory of Mind (ToM) tests. Interestingly, only participants in the educator-mediated group also showed significant improvements in Memory of Faces (MF).

A primary finding is the enhancement of ToM abilities, which improved at the post-test (T2) and were maintained at the three-month follow-up (T3). Our findings align with social-cognitive models suggesting that joint attention and joint actions are foundational to ToM development (Baron-Cohen, 1995; Mundy et al., 2009; Tomasello, 2005). By engaging in collaborative gaming, participants practiced critical social-cognitive skills such as goal interpretation and perspective-taking. The sustained improvement at T3 suggests the intervention may have fostered lasting changes, potentially establishing a foundation for ongoing social skill development.

Contrary to our hypothesis, we did not observe significant differences between the two groups and therefore cannot conclude that the peer-mediated approach was more effective. However, it is important to note that the present intervention does not fully meet the criteria of a traditional peer-mediated intervention (PMI). The evidence supporting peer-mediated training efficacy largely stems from interventions involving neurotypical peers trained or coached to actively facilitate social engagement and model appropriate interaction behaviors (Watkins et al., 2015). In the present study, peers did not receive any specific training beyond participation in the shared gaming activity. Accordingly, our findings should be interpreted not as an evaluation of a formal PMI, but rather as an exploratory comparison of the effects of interacting with a peer versus an educator within a motion-based gaming context. It is possible that each condition offered unique benefits that culminated in comparable overall outcomes. For instance, the educator-mediated approach provided a structured and scaffolded introduction to social skills, whereas cooperating with a peer presented more demanding, real-world challenges that may have spurred robust skill development through a different mechanism.

The finding that the educator-led group showed greater progress on the MF test immediately following the training is noteworthy. Performance on the MF test holds broader significance in autism research, as difficulty remembering faces is linked to social interest and adaptive skills (Hauck et al., 1998; Minio-Paluello et al., 2020). This improvement may be viewed as complementary to the ToM gains. The enhanced ability to recognize faces could have been facilitated by educators, who are more likely to explicitly direct participants' attention toward facial features. Conversely, autistic peer interactions may naturally involve less emphasis on direct facial engagement, given the social communication challenges inherent to ASD.

Finally, we observed improvements in one motor test (IP) and one visuospatial test (GP), but these changes only became significant at the T3 follow-up. Several factors could explain these delayed improvements. First, they might reflect increased familiarity with the test format rather than a true change in underlying skills, which is particularly relevant for timed tasks like the GP that rely on understanding the task structure. Second, some training effects may require a consolidation period to become evident. An improvement emerging only at follow-up could result from a longer-term process of skill assimilation. However, to disentangle the effects of the intervention from test–retest learning, further studies incorporating a control group are necessary.

Regarding quality of life, we did not observe significant changes in TACQOL scores. This could be attributed to several factors, including limitations of the instrument itself, which may lack the sensitivity to capture subtle changes in this population over a short period. Furthermore, the intervention's specific focus on social skills may not have been broad enough or long enough to impact overall well-being. It is also possible that individuals with ASD and their parents find it difficult to perceive or report small behavioral changes that have not yet generalized to daily contexts like home or school.

Although the TACQOL scale showed no significant changes, the Educator Rating Scale revealed a significant and gradual improvement across all investigated domains, including sensory tolerance, attention, communication, and relational skills. While not a standardized measure, this tailored questionnaire proved effective in capturing subtle, context-specific changes that might be overlooked by broader assessments. It served as a practical tool for monitoring day-to-day progress, reflecting the participants' real-time development in critical areas within the intervention setting.

Conclusion

In conclusion, this study demonstrates the feasibility of the motion-based training for both educator- and peer-mediated groups. A key achievement of this work is the complete retention of participants, which underscores the intervention's high level of engagement and its success in fostering social cooperation, even when quantitative outcomes were not immediately apparent. This sustained participation also provides indirect evidence of the acceptability of the intervention procedures for adolescents and adults on the autism spectrum. Our results suggest that while both the peer- and educator-mediated approaches can yield benefits, the educator's role remains fundamental for structuring the interaction and reinforcing gains. From this perspective, the motion-based technology should not be viewed as a standalone solution but rather as a mediating tool—a cornerstone of the "therapeutic triangle" (Malinverni et al., 2017) that facilitates the relationship between participants and the therapist.

However, several limitations of this study warrant consideration. First, the assessment tools may have lacked the sensitivity to capture subtle improvements in social interaction, potentially underestimating the intervention's true effects. Second, the sample's heterogeneity, which included participants with different levels of support needs, may have introduced variability that obscured more specific intervention effects. Additionally, the peer condition lacked a structured peer-training component, which limits the extent to which the intervention can be classified as a peer-mediated intervention and may have reduced its potential impact. Finally, the absence of a control group and the lack of blinding for the therapists and psychologist limit the ability to draw definitive causal conclusions about the training's efficacy.

Future research should aim to address these limitations by employing more sensitive assessment tools, recruiting more homogeneous samples, and incorporating a control group design with double-blinding to better isolate the impact of the intervention.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s41252-026-00497-x.

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Data Availability The datasets generated and analyzed during the current study are available from the corresponding author upon request.

Declarations

Ethics Approval The procedures were approved by the local ethics committee (Institutional Review Board, Department of Languages and Literatures, Communication, Education and Society, University of Udine, Prot. N. CGPER-2019-12-09-02) and conformed with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Consent to Participate All procedures applied in the present experiment were carried out with adequate understanding and the written consent of the participants. All participants provided consent to publish and report on their pseudo-anonymized data in aggregate form.

Conflicts of Interest The authors declare no competing interests.

References

American Psychiatric Association. (2000). *Diagnostic and statistical manual-text revision (DSM-IV-TRim, 2000)*. American Psychiatric Association.

Baron-Cohen, S. (1995). *Mindblindness: An essay on autism and theory of mind*. MIT Press.

Bauminger-Zviely, N. (2013). *Social and academic abilities in children with high-functioning autism spectrum disorders*. The Guilford Press.

Bauminger, N., Shulman, C., & Agam, G. (2003). Peer interaction and loneliness in high-functioning children with autism. *Journal of Autism and Developmental Disorders, 33*(5), 489–507. https://doi.org/10.1023/A:1025827427901

Ben-Zeev, D. (2014). Technology-based interventions for psychiatric illnesses: Improving care, one patient at a time. *Epidemiology and Psychiatric Sciences, 23*(4), 317–321. https://doi.org/10.1017/S2045796014000432

Bremer, E., Crozier, M., & Lloyd, M. (2016). A systematic review of the behavioural outcomes following exercise interventions for children and youth with autism spectrum disorder. *Autism, 20*(8), 899–915. https://doi.org/10.1177/1362361315616002

Butti, N., Biffi, E., Romaniello, R., Finisguerra, A., Valente, E. M., Strazzer, S., Borgatti, R., & Urgesi, C. (2024). Feasibility and efficacy of a virtual reality social prediction training in children and young adults with congenital cerebellar malformations. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-024-06349-8

Chen, X., Chen, J., Liao, M., & Wang, G. (2023). Early onset of impairments of interpersonal motor synchrony in preschool-aged children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 53*(6), 2314–2327. https://doi.org/10.1007/s10803-022-05472-8

Clearfield, M. W. (2011). Learning to walk changes infants' social interactions. *Infant Behavior & Development, 34*(1), 15–25. https://doi.org/10.1016/j.infbeh.2010.04.008

Clearfield, M. W., Osborne, C. N., & Mullen, M. (2008). Learning by looking: Infants' social looking behavior across the transition from crawling to walking. *Journal of Experimental Child Psychology, 100*(4), 297–307. https://doi.org/10.1016/j.jecp.2008.03.005

Corbett, B. A., Schupp, C. W., Simon, D., Ryan, N., & Mendoza, S. (2010). Elevated cortisol during play is associated with age and social engagement in children with autism. *Molecular Autism, 1*(1), Article Article 13. https://doi.org/10.1186/2040-2392-1-13

Dove, E., Wang, R., Zabjek, K., & Astell, A. (2020). Impacts of motion-based technology on balance, movement confidence, and cognitive function among people with dementia or mild cognitive impairment: Protocol for a quasi experimental pre- and posttest study. *JMIR research protocols, 9*(9), e18209. https://doi.org/10.2196/18209

Eisapour, M., Cao, S., & Boger, J. (2020). Participatory design and evaluation of virtual reality games to promote engagement in physical activity for people living with dementia. *Journal of rehabilitation and assistive technologies engineering, 7*, 2055668320913770. https://doi.org/10.1177/2055668320913770

Ferrari, E., Butti, N., Gagliardi, C., Romaniello, R., Borgatti, R., & Urgesi, C. (2022). Cognitive predictors of social processing in congenital atypical development. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-022-05630-y

Fitzpatrick, P., Frazier, J. A., Cochran, D. M., Mitchell, T., Coleman, C., & Schmidt, R. C. (2016). Impairments of social motor synchrony evident in autism spectrum disorder. *Frontiers in Psychology, 7*, 1323. https://doi.org/10.3389/fpsyg.2016.01323

Fitzpatrick, P., Frazier, J. A., Cochran, D., Mitchell, T., Coleman, C., & Schmidt, R. C. (2018). Relationship between theory of mind, emotion recognition, and social synchrony in adolescents with and without autism. *Frontiers in Psychology, 9*, Article Article 1337. https://doi.org/10.3389/fpsyg.2018.01337

Grossman, J. B., Carter, A., & Volkmar, F. R. (1997). Social behavior in autism. *Annals of the New York Academy of Sciences, 807*, 440–454. https://doi.org/10.1111/j.1749-6632.1997.tb51938.x

Hauck, M., Fein, D., Maltby, N., Waterhouse, L., & Feinstein, C. (1998). Memory for faces in children with autism. *Child Neuropsychology, 4*(3), 187–198. https://doi.org/10.1076/chin.4.3.187.3174

Karasik, L. B., Tamis-LeMonda, C. S., & Adolph, K. E. (2011). Transition from crawling to walking and infants' actions with objects and people. *Child Development, 82*(4), 1199–1209. https://doi.org/10.1111/j.1467-8624.2011.01595.x

Keller, R., Ardizzone, F., Finardi, C., Colella, R., Genuario, C., Lopez, M., Salerno, L., Nobile, E., & Cicinelli, G. (2022). Real-life social-skills training and motor-skills training in adults with autism spectrum disorder: The Con-Tatto Project walking down the Francigena Route. *Frontiers in Psychiatry, 13*, Article 846619. https://doi.org/10.3389/fpsyt.2022.846619

Korkman, M., Kirk, U., & Kemp, S. (2007). *NEPSY-II.* (Ed. Italiana Urgesi et al., 2011). Giunti Psychometrics.

MacDonald, M., Lord, C., & Ulrich, D. A. (2013). The relationship of motor skills and social communicative skills in school-aged children with autism spectrum disorder. *Adapted Physical Activity Quarterly: APAQ, 30*, 271–282. https://doi.org/10.1123/apaq.30.3.271

Malinverni, L., Mora-Guiard, J., Padillo, V., Valero, L., Hervás, A., & Pares, N. (2017). An inclusive design approach for developing video games for children with autism spectrum disorder. *Computers in Human Behavior, 71*, 535–549. https://doi.org/10.1016/j.chb.2016.01.018

Minio-Paluello, I., Porciello, G., Pascual-Leone, A., & Baron-Cohen, S. (2020). Face individual identity recognition: A potential endophenotype in autism. *Molecular Autism, 11*(1), 81. https://doi.org/10.1186/s13229-020-00371-0

Mubin, O., Alnajjar, F., Al Mahmud, A., Jishtu, N., & Alsinglawi, B. (2022). Exploring serious games for stroke rehabilitation: a scoping review. Disability and rehabilitation. *Assistive technology, 17*(2), 159–165.https://doi.org/10.1080/17483107.2020.176830

Mundy, P., Sullivan, L., & Mastergeorge, A. M. (2009). A parallel and distributed-processing model of joint attention, social cognition and autism. *Autism Research, 2*(1), 2–21. https://doi.org/10.1002/aur.61

Narzisi, A., Muratori, F., Calderoni, S., Fabbro, F., & Urgesi, C. (2013). Neuropsychological profile in high functioning autism spectrum disorders. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-012-1736-0

Peng, W., & Crouse, J. (2013). Playing in parallel: The effects of multiplayer modes in active video game on motivation and physical exertion. *Cyberpsychology, Behavior and Social Networking, 16*(6), 423–427. https://doi.org/10.1089/cyber.2012.0384

Pereira, F., Bermúdez I Badia, S., Jorge, C., & Cameirão, M. S. (2021). The use of game modes to promote engagement and social involvement in multi-user serious games: a within-person randomized trial with stroke survivors. *Journal of neuroengineering and rehabilitation, 18*(1), 62. https://doi.org/10.1186/s12984-021-00853-z

Portnoy, S., Hersch, A., Sofer, T., & Tresser, S. (2017). Comparison of path length and ranges of movement of the center of pressure and reaction time and between paired-play and solo-play of a virtual reality game. *Games for Health Journal, 6*(3), 147–151. https://doi.org/10.1089/g4h.2017.0017

R Core Team (2024). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org

Raven, J. C. (1936). Raven Standard Progressive Matrices (RSPM) [Database record]. *APA PsycTests*.https://doi.org/10.1037/t07027-000

Ruggeri, A., Dancel, A., Johnson, R., & Sargent, B. (2020). The effect of motor and physical activity intervention on motor outcomes of children with autism spectrum disorder: A systematic review. *Autism : THe International Journal of Research and Practice, 24*(3), 544–568. https://doi.org/10.1177/1362361319885215

Schiltz, H., Gohari, D., Park, J., & Lord, C. (2024). A longitudinal study of loneliness in autism and other neurodevelopmental disabilities: Coping with loneliness from childhood through adulthood. *Autism : THe International Journal of Research and Practice, 28*(6), 1471–1486. https://doi.org/10.1177/13623613231217337

Sipowicz, K., Pietras, T., & Kosmalski, M. (2023). Feelings of loneliness and meaning in life in subjects with Asperger's syndrome: A pilot study. *Scientific Reports, 13*, Article 17453. https://doi.org/10.1038/s41598-023-43826-z

Stansfield, S., Dennis, C., Larin, H., & Gallagher, C. (2015). Movement-based VR gameplay therapy for a child with cerebral palsy. *Studies in health technology and informatics, 219*, 153–157.

Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: The origins of cultural cognition. *The Behavioral and Brain Sciences, 28*(5), 675–735. https://doi.org/10.1017/S0140525X05000129

Urgesi, C., Campanella, F., & Fabbro, F. (2011). *NEPSY-II, Contributo alla Taratura Italiana*. Giunti OS.

Vogels, T., Verrips, G. H. W., Koopman, H. M., Theunissen, N. C. M., Fekkes, M., & Kamphuis, R. P. (1999). *TACQOL manual parent form and child form*. Leiden Center for Child Health and Pediatrics LUMC-TNO.

Wang, L. A. L., Petrulla, V., Zampella, C. J., Waller, R., & Schultz, R. T. (2022). Gross motor impairment and its relation to social skills in autism spectrum disorder: A systematic review and two meta-analyses. *Psychological Bulletin, 148*(3–4), 273–300. https://doi.org/10.1037/bul0000358

Watkins, L., O'Reilly, M., Kuhn, M., Gevarter, C., Lancioni, G. E., Sigafoos, J., & Lang, R. (2015). A review of peer-mediated social interaction interventions for students with autism in inclusive settings. *Journal of Autism and Developmental Disorders, 45*(4)Weiss, P. L., Tirosh, E., & Fehlings, D. (2014). Role of virtual reality for cerebral palsy management. Journal of child neurology, 29(8), 1119–1124. https://doi.org/10.1177/08830738145330071070–1083. https://doi.org/10.1007/s10803-014-2264-x

Weiss, P. L., Tirosh, E., & Fehlings, D. (2014). Role of virtual reality for cerebral palsy management. *Journal of child neurology, 29*(8), 1119–1124. https://doi.org/10.1177/0883073814533007

Wilcoxon, F. (1945). Individual comparisons by ranking methods. *Biometrics Bulletin, 1*(6), 80–83. https://doi.org/10.2307/3001968

World Health Organization. (1993). *The ICD-10 classification of mental and behavioural disorders: Diagnostic criteria for research. World Health Organization*.