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Communication Skills through Digital Technology in Language Learners with Autism: A Systematic Review and Meta-Analysis

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Abstract

The use of technology-based instructions and treatment tools to compensate for deficiencies in autism spectrum disorder (ASD) is evidently increasing. The present study that performed during 2021-2022 was a systematic review and meta-analysis concerning the efficacy of digital technologies in improving the deficient communication skills in language learners with ASD. Ten studies met the inclusion criteria. The results revealed that the overall effect size (Cohen's d) was 0.12 for both fixed effect model and random-effect model ($z = 1.155$, $p > 0.05$). The effect size was statistically non-significant. We also considered Magnitudes of Cohen's d fixed at 0.2, 0.5, and 0.8 which commonly accepted for small, medium and large quantities. Again, the result was not significantly different from zero and approached the small magnitude ($0.12 < 0.2$). Despite estimation of variances of effect sizes across studies (Q index, I2 and T2 values), the homogeneity in study results was approved; however, due to small number of studies included in this meta-analysis, the results may not be generalizable ($Q= 8.780$, $I2 = 0.00$, $T2 = 0.00$, $p > 0.05$). For future comparisons, we therefore recommend the use of more evidence-based experimental studies with modifications in their technology devices to secure higher statistical gains. We also recommend considering moderator variables which affected the effect size of included publications consisting age, IQ level, treatment durations and validity of the technology devices.

Keywords: Autism, Communication, Language Learning, Meta-Analysis, Technology

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Introduction

The sentenced law of 'No Child Left Behind Act' in 2001 in United States and its new version in 2016 aimed to level educational field for individuals who are disadvantaged and are receiving special educational services including those with autism. The main principle of teaching and training these exceptional individuals is that the teachers, educational content, parents, and society should be adjusted to their specific needs. The key diagnostic characteristics of autism as a lifelong neuro-developmental disorder are social, emotional, and communication impairments (APA, 2013). The communicative disorder including speech and language impairments are connected to behavioral challenges (Claudia & Lucia, 2022; Manente et al., 2022) and affect the quality of life in individuals with autism spectrum disorder (ASD) in numerous ways as feeling of loneliness, rejection and isolation in society, and academic and occupational failure (Evers et al., 2022).

Autism, as a spectrum, has ranges of severity on its continuum, with no subtypes (Lord & Jones, 2012; Rajendran, 2013; Skuse, 2012) and the intelligence quotient (IQ) as its strong predictor (Baron-Cohen et al., 2002). The impairments in communication have a universal nature in autism and exist in all ranges of autism. However, language functioning varies for different ranges of autism on its continuum. At one end of the continuum, in severe autism (classic Kanner type) children suffer from language delay and verbal inability before two years old. At the other end of the continuum, the Asperger syndrome (AS) and high-functioning autism (HFA) have many features of autism, but the IQ level is average or above average and language delay does not exist (Baron-Cohen et al., 2002; Baron-Cohen, 2004).

The most effective methods delivered to the ASD children after diagnosis in childhood use behavioral and developmental approaches (Sandbank et al., 2020). However, their administration is not easy due to the need for specialized staff, intensive time, high costs, and difficulty in preserving the effects (Rogge & Janssen, 2019; Sandgreen et al., 2021). In recent years, technology-based instructions have been successfully applied for the support and treatment of the communication skills in individuals with ASD. The methods based on technology meet the need for consistency, predictability, and the preferred reduced social interaction by individuals with ASD (Ghanouni et al., 2020). Moreover, technology-based instructions are person-specific, produce higher motivation, lower costs and control the content and rate of learning (Gillies-Walker et al., 2022; Jouen, et al., 2017). The existence of perceptual features, sound effects and action created in computers may elicit children's attention and motivation for learning (Davis et al., 2022).

A variety of terms such as computer-mediated (Esnaashari et al., 2022), computer-based (Ramdoss et al., 2011, 2012), computer-assisted (Pennington, 2010; Root et al., 2017), innovative technology-based (Grynszpan et al., 2014), technology-aided (Odom et al., 2015) and digital interventions (Sandgreen et al., 2021) have been used by growing number of research which applied innovative treatments for individuals with ASD. The treatments aimed to enhance different skills e.g., academic skills (Pennington, 2010; Root et al., 2017), communication skills (Ramdoss et al., 2011), literacy skills (Ramdoss et al., 2011), social and emotional skills (Ramdoss et al., 2012), and social and developmental skills (Sandgreen et al., 2021).

Different communication skills have been targeted by studies to be enhanced in individuals with ASD. Several studies considered the effect of computerized learning on receptive language to teach new vocabularies (Eren & Curaoğlu, 2022; Nekoobahr et al., 2021; Rogerson-Revell, 2021). Some studies focused on communication initiations (Ke et al., 2022; Walters et al., 2021). Some other studies were designed to increase production of spoken words (De Sloover, 2022; Nadel et al., 2022; Newman et al., 2021). The study by Esnaashari et al. (2022) investigated sentence imitation, diagnosis of characters' roles and setting in English as a foreign language (EFL) conversation.

Some review studies have specifically examined the effectiveness of digital technology for children with ASD to teach or train their communication skills. Blischak and Schlosser (2003) reviewed the research involving word processing software with synthetic speech capabilities and found that computer-based instruction (CBI) using this software is a potential means for improving the spelling and frequency of spontaneous utterances of individuals with ASD. Ramdoss et al. (2011)'s systematic search provided 10 studies published from 1995 to 2010, involving the use of CBI to enhance communication skills in individuals with ASD. However, the study revealed its limitation with respect to the inclusive extent of the existing literature. The review also indicated the need for more specially designed and qualified digital devices for improving different types of communication skill in individuals with ASD.

Later review studies focused on digital technology and communication skills have specified their analysis to publications with specified digital technologies (Dechsling et al., 2021; Howard & Gutworth, 2018; Leung et al., 2021; Lorah et al., 2014; Mosher et al., 2021). A systematic review and meta-analysis that specifically explores the effect of the vast technology devices on communication skills of ASD to date is of relevance. The goal of present study was to conduct a systematic review and meta-analysis of digital technologies for those with ASD by assessing a) the digital technology treatments used, b) the targeted skills, and c) the overall effect size (Cohen's d) of the digital devices used in treatments.

Method

Study Design

This study was a systematic review and meta-analysis concerning the effectiveness of the experimentation of digital technologies in training communication skills in ASD. The Preferred Reported Items for Systematic reviews and Meta-analyses (PRISMA) standard used as an evidence-based model with minimum set of items to ensure a clear and complete reporting of the study selection process (Moher et al., 2009).

Search Procedure

A systematic literature search was conducted to find scientific papers published in peer reviewed journals on the databases Springer Link, Google scholar, Science Direct and Pro- Quest. In our search query we considered the articles including the keywords 'autism', 'technology', 'communication' and variations of these that could answer our research question. Furthermore, the list of references of our found articles were manually checked to find those which were relevant to our search categories. The search was conducted considering the articles published between 2011 and 2022 in English language and produced 355 articles allocated in this time span. The abstracts of the articles were screened and narrowed down to 10 final appropriate articles for this step.

Selection Procedure

The abstract and full-text screening of articles was performed by two evaluators and those articles which met the inclusion criteria were selected. Discrepancies between evaluators were resolved through consensus. Coding for the inclusion was based on the use of the following criteria: a) treatments concerned with computerized learning in autism, b) participants diagnosed with ASD according to the DSM-V (American Psychiatric Association), c) treatments targeted for training or measurement of communication skills in autistic individuals, d) training assessed based on pre- and post-test designs using both experimental and control groups with autism. The exclusion criteria applied both during selection and data extraction procedures included: a) reliance on single- or multiple single-case design due to lower strength of evidence (Ben-Sasson, 2013; Kossyvaki, 2020 ; Murdock et al., 2013; Xin & Leonard, 2015), b) comparison of two interventions (Crowell et al., 2019) which conceals the potential effect size (Cohen's *d*) that is based on calculation of differences of outcomes of experimental and control groups and, c) involvement of parents, carers, teachers or school or clinic staff members as the participants of the study (Silvera-Tawil et al., 2018). Table 1 shows data extraction considering details of the included studies to assess the efficacy of digital treatments for individuals with ASD.

Data Analysis

We used the reported means, standard deviations and sample sizes of experimental and control groups to calculate Cohen's *d* and Hedges' *g* effect sizes for all studies. We contacted the authors, if effect sizes could not be found or calculated. Magnitudes of Cohen's d were fixed at 0.2, 0.5, and 0.8, respectively as commonly accepted for small, medium and large (Zakzanis, 2001).

As noted by Li and Wang (2018, in Phakiti et al., 2018), effect sizes are the building blocks of meta-analysis. They defined effect sizes as standardized indices that enable researchers to compare the results obtained in different studies. The importance of effect sizes can be better understood under the theory of null-testing hypothesis (Field, 2018) that says if the sample size is large, smallest difference and/ or lowest correlations are flagged as significant, whereas in large samples biggest differences and/or correlations may be stated as non-significant. To overcome this problem, the statistical technique of effect size was invented. As noted by Field (2018, p 174-75), "An effect size is an objective and (usually) standardized measure of the magnitude of observed effect".

The Comprehensive Meta-Analysis Software (CMS) produces two effect size indices; Cohen's *d* and Hedges' *g* (from now on δ). The latter index is preferred over the former one if the sample size is small. As elaborated in CMS manual (Borenstein et al., 2009, p 51), "It turns out that Cohen's *d* has a slight bias, tending to overestimate the absolute value of δ (effect size) in small samples. This bias can be removed by a simple correction that yields an unbiased estimate of δ, with the unbiased estimate sometimes called Hedges' g". It should also be noted that the negative signs of the effect size indices can be ignored. The negative sign means that the experimental group's mean was lower than the control group's mean. As an example, Kim et al. (2014) reported means of 18.06 and 19.26 for experimental and control groups. Since the first mean was smaller, the reported Hedges's *g* value of -0.281 was negative.

To find out whether the effect sizes were significant, i.e., $p > 0.05$, the Cohen's *d*, their lower- and upper- 95 percent confidence intervals, *z*-scores, and probabilities for the ten synthesized studies were calculated. The computations were made based on two models; fixed and random effect models. The fixed model assumes that any variation in dependent variable communication skill was due to the treatment digital technology, whereas random effect model assumes that extraneous factors might also have affected the results, factors such as intelligence, motivation, social status, gender etc. Our meta-analysis used the Forest plot diagram to show these results graphically.

To find out generalizability of the results, the *Q* Test of Homogeneity of Effect Sizes was computed. The *Q*, tau squared (T^2), and I squared (I^2) values are reported for the fixed effect model. Despite these statistics are based on the fixed effect model, they are commonly applied to the random effect model as well. The second point is that the probability associated with the *Q* statistics is applied to T^2 and I^2 as well.

Journals publishing results of Meta-analyses and/or researchers running meta-analysis opt for including studies with small sample sizes whose effect size are large and consequently their probabilities for significant differences or correlations are lower than 0.05 (Borenstein et al., 2009; Boulton & Cobb, 2017; Vitta & Al-Hoorie, 2020; Yousefi & Biria, 2018). The publication bias (selection bias) explores such a bias. There are both graphical and statistical methods to check for any publication bias.

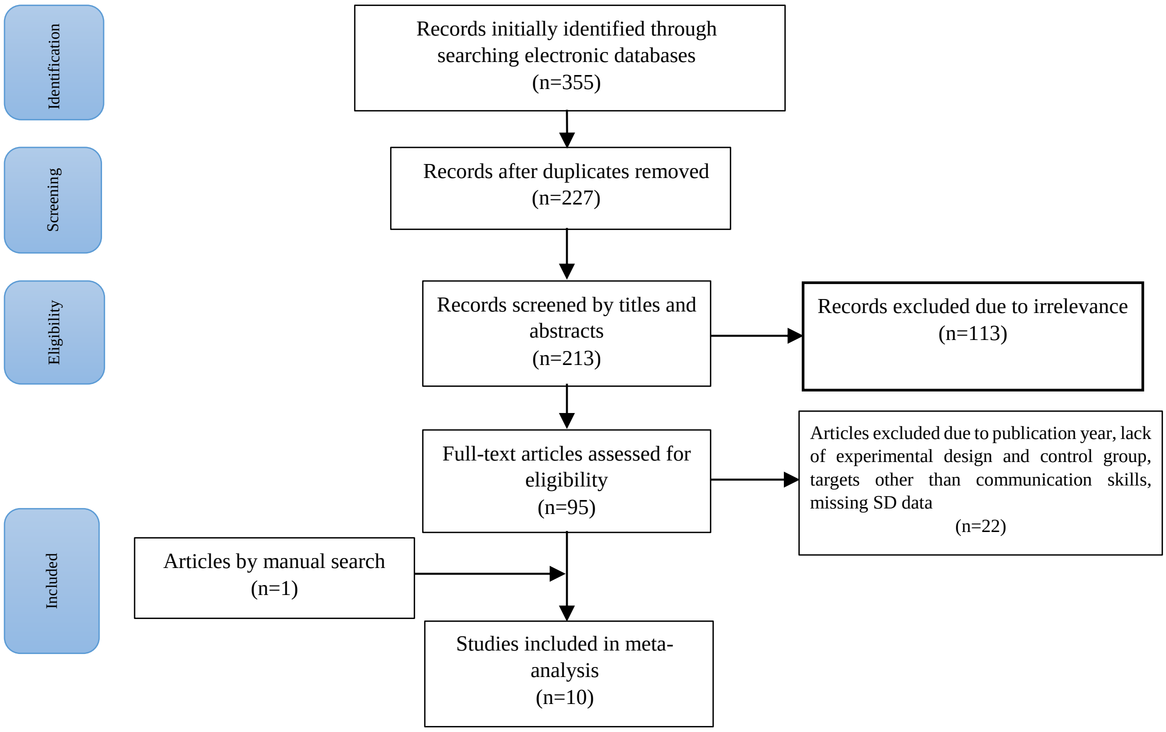
We investigated existence of publication bias using the Funnel plot. Large studies with small effect sizes are plotted on the top and small studies with large effect sizes are plotted at the bottom. Absence of any publication bias can be proved if the Funnel plot is symmetrical (Chen & Peace, 2013) with large studies cluster around the mean effect size on the top and smaller studies spread across wider range near the bottom" (Yousefi & Biria, 2018, p. 18). On the other hand, presence of publication bias can be proved when the Funnel plot is skewed and asymmetrical (Chen & Peace, 2013). This type of distribution would reflect the tendency for smaller studies with larger than average effect sizes to be selected for meta-analysis, making them more likely to achieve statistical significance. Funnel plots are criticized for being subjective as noted by Cummings (2012, p. 268), "Of course it's rather subjective to examine the Funnel plot and judge whether you think there's much sign of publication bias, and the method usually isn't sensitive to small amounts of bias". There are four empirical methods to estimate existence of any publication bias; a) classic (Rosenthal's) fail-safe N, b) Orwin's fail-safe N, c) Duval and Tweedie's trim and fill; and finally, Begg and Mazumdar rank correlation. Based on these criteria, it can be decided how many more studies need to be included to support the null-hypothesis as no significant difference between effect sizes. In other words, how many missing studies are required to bring the *p*-value higher than alpha, i.e., $p > 0.05$.

Findings

The present study was an attempt to synthesize publications that investigated the effect of digital technology on communication skills of individuals with ASD. Figure 1 shows a PRISMA flow chart of the study selection procedure. Thirteen publications attained the selection criteria. However, due to inability to find or calculate the effect size despite e-mailing the authors, three studies were discarded (Bauminger et al., 2013; Moro et al., 2019; Voss et al., 2019). Finally, ten studies were included in our meta-analysis.

Figure 1

Flow Chart Showing the Preferred Reported Items for Systematic Reviews and Meta-Analyses (PRISMA) Checklist



The resulting ten studies included 375 participants with ASD. The studies reported means, standard deviations, and sample sizes. The studies targeted different types of communication skills including emotion and gaze recognition (Bekele et al., 2011; Hopkins et al., 2011; Jarrold et al., 2013; Kim et al., 2014; Yuan & IP, 2018; Yun et al., 2017), social skills (Fletcher -Watson et al., 2016; Jouen et al., 2017, Kim et al., 2014; Lorenzo et al., 2019, Stichter et al., 2014, Yuan & IP, 2018), executive functioning (Stichter et al., 2014) and social confidence and motivation (Bekele et al., 2011; Kim et al., 2014; Stichter et al., 2014).

The variety of technology devices were used in studies including virtual reality (VR) (Bekele et al., 2011; Jarrold et al., 2013; Kim et al., 2014; Stichter et al., 2014; Yuan & IP, 2018), iPad apps (Fletcher-Watson et al., 2016), computer programs (Hopkin et al., 2011; Jouen et al., 2017), Android phone apps (Lorenzo et al., 2019), and robots (Yun et al., 2017). Table 1 shows the characteristics of all the included publications in this study.

Table 1.

Details of the Included Studies Used to Assess the Efficacy of Digital Technologies for Individuals with ASD

References (year)	Treatment condition					control condition					Technology used	Targeted skill(s)
	Mean age in years (SD)	Sample size	Diagnosis	Exp.Mean	Exp. SD	Mean age in years (SD)	Sample size	Diagnosis	C. Mean	C. SD		
Fletcher-Watson et al. (2016)	4.1 (0.9)	26	ASD	24.90	6.00	4.16 (1.1)	27	ASD	24.90	5.20	Tablet app Find Me	Social communication skills

References (year)	Treatment condition					control condition					Technology used	Targeted skill(s)
	Mean age in years (SD)	Sample size	Diagnosis	Exp.Mean	Exp. SD	Mean age in years (SD)	Sample size	Diagnosis	C. Mean	C. SD		
Hopkins et al. (2011)	10.31 (3.31)	11	HFASD & LFASD	55.09	20.91	10.57 (3.2)	14	HFASD & LFASD	54.79	16.41	Face Say computer program	Emotion and facial recognition
Bekele et al. (2011)	14.7 (1.1)	10	ASD	16.30	2.67	14.6 (1.2)	10	TD	14.50	3.78	VR-based facial affect presentation using the game engine Unity	Facial affect recognition, response latency, gaze patterns & confidence
Jarrold et al. (2013)	14.16 (1.5)	37	HFASD	1.40	0.80	13.84 (1.3)	54	TD	1.20	0.80	Virtual classroom via 4 screens, half-CAVE VR & middle VR, eMagin Z800 3DVisor HMD & 21.8-inch monitors	Social attention, gaze duration and fixation
Kim et al. (2014)	11.1 (2.5)	19	HFASD	18.06	4.44	11.5 (2.3)	23	TD	19.26	3.97	Virtual Reality Emotion Sensitivity test (V-REST) Reading the Mind in the Eyes (RME) task	Social motivation, emotion recognition and interpersonal distance
Lorenzo et al. (2019)	3.88 (1.16)	6	ASD	6.50	3.71	4.1 (1.23)	5	ASD	5.30	3.10	Quiver vision app & Android phone	Relationship skills and flexibility
Yun et al. (2017)	5.75 (0.88)	8	ASD	15.75	6.04	6.32 (1.23)	7	ASD	12.29	4.35	Robotic system	Eye-contact & facial emotion recognition
Yuan & II (2018)	8.9 (1.1)	36	ASD	20.20	3.00	8.7 (1.1)	36	ASD	18.90	3.50	Four-sided CAVE Automatic Virtual Environment (CAVE)VR Goggles	Emotional & social skills
Stichter et al. (2014)	12.57 (0.75)	11	ASD	78.18	38.52	12.57 (0.75)	11	ASD	92.82	36.70	iSocial 3D collaborative virtual learning environment (VLE)	Social competence, executive functioning & motivation
Jouen et al. (2017)	6.85 (1.34)	14	ASD	2.90	2.10	7.17 (1.62)	10	ASD	3.70	1.60	Computer program with automated serious gaming platform GOLIAH (gaming open library intervention in autism at home)	Communication & social interaction

Note. SD Standard deviation, *ASD* Autism sectrum disorder, *HFASD* High-functioning autism spectrum disorder, *LFASD* Low-functioning autism spectrum disorder

As shown in Table 1, the experimental group's means ranged from a low of 1.40 (Jarrold et al., 2013) to a high of 78.18 (Stichter et al., 2013) and their standard deviations ranged from 0.80 (Jarrold et al., 2013) to 38.52 (Stichter et al., 2013). Jarrold et al. (2013) showed the lowest mean and standard deviation for the control group (M = 1.20, SD = 0.80) while Stichter et al. (2013) showed the highest statistics (M = 92.82, SD = 36.70) for the control group. For both experimental and control groups, Lorenzo et al. (2018) had the lowest sample sizes of 6 and 5 whereas Jarrold et al. (2018) had the highest sample sizes of 37 and 54.

Table 2 displays the Cohen's *d* and Hedges' *g* effect sizes, their standard errors and also the differences between two groups' means, plus their standard errors.

Table 2

Cohen's d, Hedges's g, Mean Differences and their Standard Errors

Study name	Cohen's d	Std. Err	Hedges's g	Std. Err	Difference in means	Std. Err
Fletcher Watson et al. (2016)	0.000	0.275	0.000	0.271	0.000	1.540
Hopkins et al. (2011)	0.016	0.403	0.016	0.390	0.300	7.454
Bekele et al. (2014)	0.550	0.456	0.527	0.436	1.800	1.463
Jarrold et al. (2018)	0.250	0.214	0.248	0.212	0.200	0.171
Kim et al. (2014)	-0.287	0.312	-0.281	0.306	-1.200	1.298
Lorenzo et al. (2018)	0.348	0.610	0.318	0.558	1.200	2.090
Yun et al. (2017)	0.650	0.531	0.611	0.500	3.460	2.757
Yuan & IP (2018)	0.399	0.238	0.395	0.235	1.300	0.768
Stichter et al. (2013)	-0.389	0.430	-0.374	0.414	-14.640	16.042
Jouen et al. (2017)	-0.419	0.418	-0.404	0.404	-0.800	0.791

Based on the results in Table 2, it can be concluded that Yun et al. 2017 (d = 0.650, δ=.611), Bekele et al. (2014) (d = 0.550, δ = 0.527), Jouen et al. 2013 (d = .419, δ = 0.404), and Yuan and IP (2018) (d = 0 .399, δ = 0.395) had the highest effect size values, while Hopkins et al. (2011) (d = 0.016, δ = 0.016) and Fletcher-Watson et al. (2016) (d = 0.000, δ = 0.000) had the lowest effect sizes.

Table 3 displays the Cohen's *d*, their lower- and upper- 95 percent confidence intervals, *z*-scores, and probabilities for the ten synthesized studies. The results indicated that none of the effect sizes were significant (p > 0.05). Thus, it can be concluded that the digital technologies did not have any significant effect on communication skills. In other words, the mean differences discussed in Table 2 did not show any significant differences between the experimental and control groups' means across ten studies.

Table 3

Hedge's g, 95 % Confidence Intervals and Probabilities

Study	Cohen's d	Std. Err	V	Lower	Upper	Z	p
Fletcher-Watson et al. (2016)	0.000	0.275	0.075	-0.539	0.539	0.000	1.000
Hopkins et al. (2011)	0.016	0.403	0.162	-0.773	0.806	0.040	0.968
Bekele et al. (2014)	0.550	0.456	0.208	-0.343	1.443	1.207	0.227
Jarrold et al. (2018)	0.250	0.214	0.046	-0.170	0.670	1.167	0.243
Kim et al. (2014)	-0.287	0.312	0.097	-0.897	0.324	-0.920	0.358
Lorenzo et al. (2018)	0.348	0.610	0.372	-0.848	1.543	0.570	0.569
Yun et al. (2017)	0.650	0.531	0.282	-0.391	1.690	1.223	0.221
Yuan & IP (2018)	0.399	0.238	0.057	-0.068	0.865	1.675	0.094
Stichter et al. (2013)	-0.389	0.430	0.185	-1.233	0.454	-0.904	0.366
Jouen et al. (2017)	-0.419	0.418	0.175	-1.239	0.402	-1.000	0.317
Fixed	0.121	0.105	0.011	-0.084	0.326	1.155	0.248
Random	0.121	0.105	0.011	-0.084	0.326	1.155	0.248

The last two rows in Table 3 showed the results of fixed and random effect models. The results showed that the effect sizes for fixed and random effect models were 0.121. Both effect sizes were statistically non-significant, i.e., fixed-effect model (z = 1.155, $p > 0.05$), and random-effect model (z = 1.155, $p > 0.05$). Thus, it can be concluded that the synthesized studies showed that digital technology did not have any significant effect on communication skill. Forest Plot in figure 1 graphically shows the results discussed above. As it was mentioned earlier, the treatment administered in these studies did not have any significant effect on communication skill, i.e., $p > 0.05$.

Figure 2

Forest Pot of Hedge's g and 95 Percent Confidence Intervals

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Fletcher Watson et al. 2016	0.000	0.275	0.075	-0.539	0.539	0.000	1.000
Hopkins et al. 2011	0.016	0.403	0.162	-0.773	0.806	0.040	0.968
Bekele et al. 2014	0.550	0.456	0.208	-0.343	1.443	1.207	0.227
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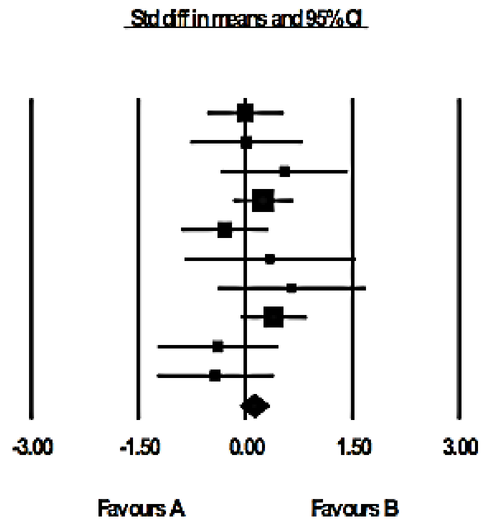
	0.121	0.105	0.011	-0.084	0.326	1.155	0.248



The Q Test of Homogeneity of Effect Sizes was computed to investigate whether the effect sizes varied significantly across studies or not. The non-significant results of the Q index displayed in Table 4, Q = 8.780, $p > 0.05$) indicated that effect sizes did not vary significantly across studies. $T^2 = 0.00$ which refers to the estimation of the variance of effect sizes indicated the variations in effect sizes were not sizable. The I^2 statistic (Higgins et al., 2003) was 0.00 which indicated that zero proportion of the between-effect size variance reflected real differences in effect sizes. In other words, 100 (100-0.00 =100) percent of differences were random i.e., due to error.

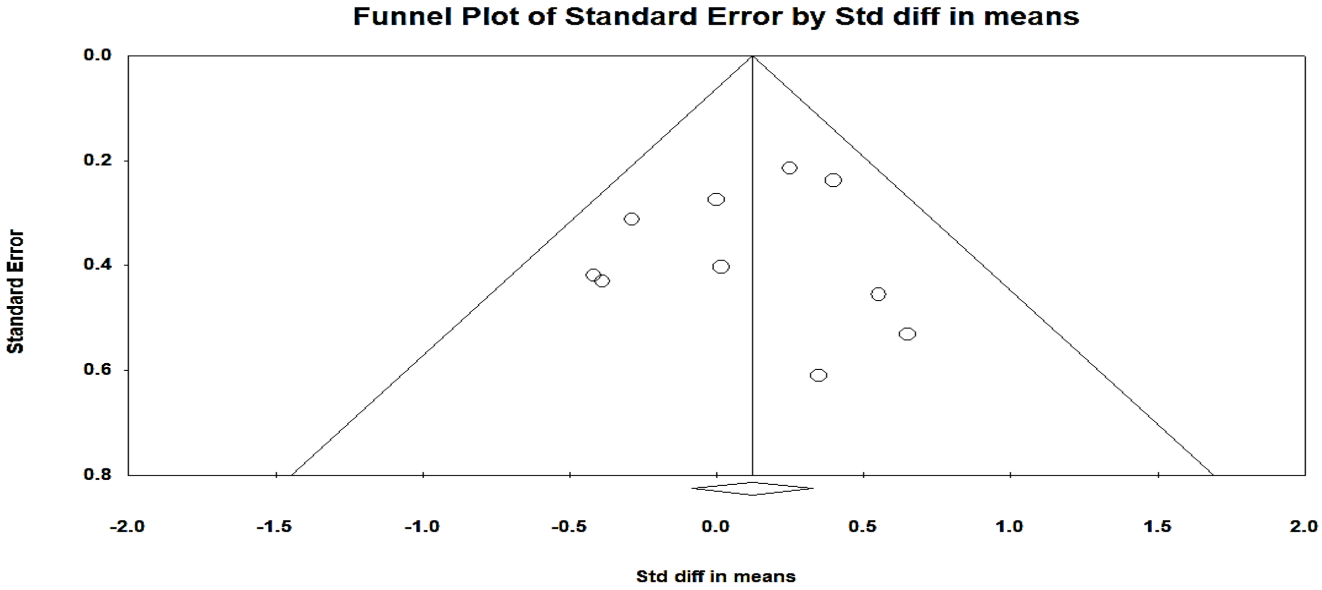
Table 4

Q, Tau Squared and I Squared Statistic

Model		**Effect Size and 95 % Confidence Intervals**					**Test of Null (2-tailed**		**Heterogeneity**				**Tau-Squared**			
	#Studies	Point Estimate	SE	V	Lower	Upper	Z	P	Q	df(Q)	P	I-Sq	Tau-Sq	SE	V	Tau
Fixed	10	.121	.105	0.011	-.084	0.326	1.155	0.248	8.780	9	0.458	0.00	0.00	.054	0.03	0.00
Random	10	.121	.105	.011	-.084	0.326	1.155	0.248								

Figure 3 indicated exercise of publication bias for the inclusion of the ten research in this study. The distribution of studies was skewed; moreover, they clustered on the top and around the mean, leaving the lower part of the figure for smaller sample sizes empty. These results suggested that the present meta-analysis suffered from publication bias.

Figure 3
Funnel Plot of Standard Errors by Hedge's g



To remove subjectivity that's typical assigned criticism for Funnel plots from our judgment about publication bias, (Cummings, 2012) the four empirical methods were also used to estimate existence of any publication bias; a) classic (Rosenthal's) fail-safe N, b) Orwin's fail-safe N, c) Duval and Tweedie's trim and fill; and finally, Begg and Mazumdar rank correlation. Based on these criteria, it can be decided how many more studies need to be included to support the null-hypothesis as no significant difference between effect sizes. In other words how many missing studies are required to bring the *p*-value higher than alpha; i.e., p > .05. Table 5 displays the results of the classic (Rosenthal's) fail-safe N. The results (N = zero, z = 1.96, p > 0.05) showed that zero studies are needed to be added to the present meta-analysis to yield a statistically non-significant result. Thus, classical fail-safe test would be a small one. As it was discussed above, no more studies are required to decrease the effect size down to zero.

Table 5
Classical Fail-Safe N

Z-value for observed studies	0.967
P-value for observed studies	0.333
Alpha	0.05
Tails	2.00
Z for alpha	1.96
Number of observed studies	10
Number of missing studies that would bring p-value to > alpha	0.000

The classic fail-safe test is criticized for being based on statistical significance rather than magnitude of significance (Borenstein et al., 2009). The results of Orwin's fail-safe test (Table 6) indicated that two more studies should be included to reduce the effect size to below 0.40 i.e., minimum criterion for an effective educational treatment (Vita & Al-Hoorie, 2020).

Table 6
Orwin's Fail-Safe N

Hedge's g in observed studies	0.1208
Criteria for a 'trivial' hedges' g	0.10
Mean hedge's g in missing studies	-0.10
Number missing studies that would bring p-value to > alpha	2.00

Trim and Fill method is closely related to the Funnel plot. It was mentioned earlier that if publication bias has been exercised, one would expect an asymmetrical Funnel plot with small studies which have large effect sizes, condensed on the right of the mean leaving a few studies on left side of the plot. Trim and fill test imputes the missing studies on the left side of the plot and computes the overall effect size anew. As displayed in Table 7, trim and fill method imputed zero studies. Thus, the effect size values of 0.12, for both fixed and random models did not change. Based on these results, it can be concluded that imputed studies resulted in reduction of effect size value less than 0.40. Recall that 0.40 is the minimum criterion for an effective educational treatment (Vitta & Al-Hoorie, 2020).

Table 7
Trim and Fill Test

		Fixed Effects			Radom Effects			Q Value
	Studies Trimmed	**Point Estimate**	**Lower Limit**	**Upper Limit**	**Point Estimate**	**Lower Limit**	**Upper Limit**	
Observed		0.1208	-0.842	0.325	0.1208	-0.842	0.325	0.878
Adjusted	0	0.1208	-0.842	0.325	0.1208	-0.842	0.325	0.878

Table 8 displays the results of the Begg and Mazumdar's rank correlation test which shows the rank correlations between effect sizes and their standard errors. If the results of the rank correlation are non-significant, as is the case in this study, it can be concluded that there was no evidence of publication bias. The results of the rank correlation indicated that there were not any significant correlations between rank of effect size and their standard errors without continuity correction (τ =0.066, z = 0.268, p > 0.05), and with continuity correction (τ = 0.044, *z* = .178, *p* > 0.05). Thus, the results of the Begg and Mazumdar's rank correlation was not evidence of publication bias. However, the results should be interpreted cautiously as noted by Janhavi et al. (2017) who believe that the Begg and Masumdar method is powerful for synthesizing 75 or more studies. Thus, the test loses its power for sample size below 25.

Table 8
Begg and Mazumdar Rank Correlations

	Without Continuity Correctio	With Continuity Correctio
Tau	0.066	0.044
z-value for tau	0.268	0.178
p-value (1-tailed)	0.394	0.429
p-value (2-tailed)	0.788	0.858

Discussion

A lot of review studies suggested potential of digital technology such as immersive technology (Dechsling et al., 2021; Howard & Gutworth, 2019; Mosher et al., 2021), tablet computers and portable media players (Lorah et al., 2014), and mobile technology (Leung et al., 2021) to improve skills such as social skills (Alzrayer et al., 2014 ; Leung et al., 2021; Ramdoss et al., 2011), cognitive skills (Leung et al., 2021), academic skills (Root et al., 2017) and language development (Ploog et al., 2012) for ASD.

The computer-mediated instructions incorporate the qualities in behavioral and cognitive views for education in autism (Parsons & Mitchell, 2002). The noble design and graphics in computers make a three-dimensional realistic setting. Hence, autistic individuals can imagine the objects and people. The user can role-play in a setting designed to simulate scenarios in reality and substitute the deficiency of imitation in autism. While imitation is not an essential requirement in normal language acquisition (Bloom & Lahey, 1978), it may play a critical role in language development of individuals with ASD. The problem with the interactive nature of communication is due to autistic individuals' deficits in imitation and joint attention as parts of the premises underlying social understanding (Jouen et al., 2017). The theory underlying this impairment in autism is the theory of mind hypothesis (Baron-Cohen, Leslie, & Frith, 1985; Premack & Woodruff, 1978) that is based on the mentalizing capability which leads to meaningful interactions in humans. The major elements involved in empathy skills are to recognize the mental states of self and others, sympathizing with others through appropriate reactions (Baron-Cohen, Wheelwright, Lawson, Griffin, & Hill, 2002), and understanding their motives and predict their actions (Parsons & Mitchell, 2002). The impaired mentalizing capability is the underlying reason for the social and communicative impairments in autism. In communications, it is important for the listeners to extract the underlying meaning in the speech using the context and their understanding of mental state of speakers to fill in the gaps of conversation. This task is especially difficult for individuals with autism (Parsons & Mitchell, 2002).

Ramdoss et al. (2011) who focused on communication skills among other skills for ASD included limited studies and more specific designs as randomized controlled trials (RCT) and studies with qualified devices. Although later other review studies were conducted with the same subject, those studies were limited to specific digital devices and hence their findings were not conclusive about the effect of the extensive area of digital technology on communication skills for ASD.

In Grynszpan et al. (2014), most of the technology-based interventions were found as being computer-based and in addition to social skills they included literacy skills. Besides, some of the publications in this study which targeted on social skills involved two groups receiving interventions to be compared in their efficacy to improve the target skill. Therefore, these publications were excluded from our meta-analysis. Sandgreen et al. (2020)'s study included 19 studies with 11 ones using treatments to improve social skills. Some of these studies were excluded due to their comparison of their intervention in experimental group with traditional instruction in control group.

The review study by Mosher et al. (2021) synthesized and compared publications which used virtual reality (VR), augmented reality (AR), mixed reality (MR), and extended reality (XR) to improve social skills in students with ASD. Despite the similarity of study subject to our meta-analysis, most of the reviewed publications were excluded due to their incompatibility with the inclusion criteria in our meta-analysis such as having a single subject design, multiple baseline design across subjects and comparison of interventions in two groups or lack of a control group.

Among the articles found in databases, those which met inclusion criteria were initially identified and then those which were appropriate in terms of the quality of their design were selected. Since we had confined our meta-analysis to use publications relevant to communication skills in ASD as their target and computation of effect size using means and standard deviations in both control and experimental groups, we finally included only ten studies meeting our inclusion criteria. Cohen's *d* in all individual studies were between 0.00 to 0.65. The overall mean effect size of studies was 0.12 which was above zero and below magnitude of 0.2, hence showing a small effect size and could not prove significant efficacy of the digital technologies applied to improve communication skills in those with ASD. Despite estimation of variances of effect sizes across studies (Q value, I^2 and T^2) approved homogeneity in study results, due to small number of studies included in this meta-analysis the results may not be generalizable. The small number of studies also may be the cause for the skewed distribution of studies leading to publication bias.

The earlier meta-analysis by Sandgreen et al. (2020) found an overall effect size, Cohen's *d* of 0.32 indicating a significant medium effect. Although the sample size was small in Sandgreen (2020)'s study, the effect was strong enough to be inferred. The differences in inclusion criteria of the present and the earlier study can justify the difference between significance found in their results. The results in our meta-analysis were below expectations, which was due to targeting communication skills which are confined area of social and linguistic skills. However, Sandgreen (2020)'s study targeted different types of deficient skills in ASD.

Conclusion

The computer-based imitation training may be advantageous for individuals with ASD for it provides visual and auditory qualities (Bernard-Optiz et al., 1999). It also supports the assumption that computers are inherent to evoke speech in non-verbal children with ASD through visualizing sounds (Jordan, 1988).

Vocalization through computer-based training (Koegel et al., 1987; Bernard-Optiz et al., 1999) makes natural language interactions accompanied with vocal imitations. Besides, visual feedback to sounds helps them to understand and imitate the conversation between characters.Given that the results in our meta-analysis are based on a limited number of studies, the non-significant results are not generalizable. The pronounced variety in technology devices used, treatment durations, and participants' age and IQ level may be the other variables which affected the effect size in each study and their consideration may lead to more comprehensive results. For a conclusive comparison, research in the area of digital technology for ASD is still too young and heterogeneous. The results from such analyses should consequently be treated with the utmost caution.

Finally, a number of potential limitations need to be considered. In spite of our comprehensive search, some relevant publications may have been ignored. Also, there may be some newly arrived ones which are not added. Also, the present study only included the publications which had mentioned standard deviation of groups to calculate Cohen's *d.* We had to exclude those which did not inform about standard deviation despite contact with their authors, although meeting other inclusion criteria. Another limitation in this study was that we could not get all needed information in some publications about baseline differences. Provision of this information may skew the effect size. Also, some studies did not perform follow-up sessions to assess the maintenance of effects. The picture is thus still incomplete and hence our study suffers from publication bias.

Contrary to expectations, we did not find a significant effect size in our meta-analysis. This study has gone some way towards our understanding of the area of digital technology and communication skills for ASD. We hope that future work will look into factors that may have yielded this weak effect including the validity of technology devices, the condition of practice (school, clinic, …), duration of practice and participants' age and IQ level.

Conflicts of Interest

No conflicts of interest declared.

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