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Virtual Reality-Based Intervention for Developmental Functioning in ASD: A Meta-Analysis

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자폐스펙트럼장애에서 발달 기능을 위한 가상현실-기반 중재: 메타분석

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ABSTRACT

This meta-analysis aggregated and analyzed the research in studying the pretest-posttest outcomes of VR-based interventions for children and young adults with ASD. Seven studies published between 2009 and 2019 with a total of 150 participants were included. Outcome measures of social competences were classified into 5 categories. The random-effects model of the current meta-analysis showed that the average effect of VR-based intervention as follows: social skills(g = .59, SE = .12, 95% CI: .35-.82), emotion recognition(g =. 50, SE = .16, 95% CI: 0.19-.82), attention(g = .35, SE = .14, 95% CI: .07-.63), executive function(g = .52, SE = .12, 95% CI: .28-.77) and conversational skills(g = .46, SE = .21, 95% CI: .05-.88). The implication for VR-based interventions for ASD was discussed with respect to environmental factor such as age, ASD functioning, number of sessions, country where the study conducted and additional treatment combined.

Keywords: *ASD, virtual reality, social skills, attention, emotion recognition, executive function, conversational skills*

According to the Korean Ministry of Health and Welfare's 「Fact-finding Survey of Persons with Disabilities」 in 2017, the prevalence rate of autism spectrum disorder is gradually increasing to 0.01 percent in 2011, 0.02 percent in 2014 and 0.03 percent in 2017. According to the Health and Welfare Ministry's 「Status of Registration as Persons with Disabilities」 in 2018, the number of children with disabilities (ages below 17) is 72,260 and among them, about 17.4 percent, or 12,559 children present with autism spectrum disorder(ASD). With the increasing number of children with ASD, the development and implementation of various interventions are being studied at home and abroad (Lee, 2018). To implement effective interventions for children with ASD, it is crucial to evaluate newly introduced interventions.

The fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013) made changes on autism diagnosis. The diagnosis is called ASD, which no longer distinguishes subdiagnoses (Autistic Disorder, Asperger Syndrome, Pervasive Developmental Disorder Not Otherwise Specified, Disintegrative Disorder) that were in the DSM-IV. Children with ASD exhibit delay or impairments in social behavior and communication including social orienting, joint attention, emotion recognition and expression, verbal and non-verbal communication (Wenar & Kerig, 2000). Associated features including abnormal responses to sensory stimuli, deficits in theory of mind, central coherence, and executive functions are often seen as well (Wicks-Nelson, Israel, 2013).

The interest in the utility of virtual reality(VR) as a treatment tool has been relatively recently increased, and VR-based interventions have been applied for a wide range of disorders such as PTSD, OCD, phobias, as well as ASD (Mesa-Gresa et al., 2018). Especially, VR-based interventions showed advantages for people with ASD because of the ecological validity of the intervention, in which the environment could be manipulated to suit the characteristics of the individuals (Jarrold et al. 2013). For example, VR interventions were developed to involve the participants with ASD in life-like contexts such as classrooms, peer groups, and meeting new people. The intervention was provided with a computer set up, a half-CAVE design, or a 3D VR technology. By setting up multiple social environment and partners, the possibility of generalization of the treatment into a real life context can be increased. Meanwhile, VR technology to improve for VR based interventions was noted by researchers. This, for example, includes difficulties in displaying immediate facial emotions and dizziness caused by a lack of reality. It may also be a limitation of VR-based interventions that clinicians and caregivers need to be trained in order to use the technology appropriately.

Previous researches on virtual reality in technology, rehabilitation and mental health (Mesa-Gresa et al., 2018; Miller & Bugnariu, 2016; Wass & Porayska-Pomsta, 2014) contributed to reveal the usefulness of VR as a diagnostic tool. However, to our knowledge, since VR-based interventions have been introduced, their effectiveness as an intervention tool for autism spectrum disorders has not been analyzed. The current study aimed to synthesize previous studies of VR as an intervention tool for ASD.

Method

Study selection

Studies of VR based interventions administered to children and young adults with ASD were selected for the analysis. For the data, following databases are searched: ERIC, PubMed, Cochrane, psycINFO and EBSCOhost from 2009 to 2019. The searches included the terms "virtual reality" or "virtual" in combination with "autism", "asd", or "aspergers". Review papers were searched in order to find any missing data as well. Subjects were limited to the children and young adults. Studies meeting the following criteria were included: 1) at least one VR-based intervention, 2) pre and post treatment tests and 3) subjects with ASD. A total of 7 studies with a total sample size of 150 participants (mean age = 14.29 year) met the final inclusion criteria and were included.

The following studies were excluded according to the following reasons: studies that did not use VR as an intervention tool (Bystrova et al., 2019; Cai et al., 2017; Chia & Kee, 2014; Lahiri et al., 2011) studies with post-test only (Jarrold et al., 2013; Ke & Moon, 2018; Kuriakose & Lahiri, 2015; Wallace et al., 2017; Wallace et al., 2010; Wang & Reid, 2013; Wang et al., 2016); studies that did not evaluate disorder related skills or symptoms (Zhao et al., 2018); studies that used a single subject (Cheng et al., 2015; De Luca et al., 2019; Stendal & Balandin, 2015) and studies in which insufficient statistical data were available (Beach & Wendt, 2015; Lahiri et al., 2012; Lorenzo et al., 2016; Millen et al., 2014; Moon & Ke, 2019; Politis et al., 2017). See Fig. 1 for a diagram of the study selection process.

All analyses were completed with the Comprehensive Meta-Analysis software version 3.

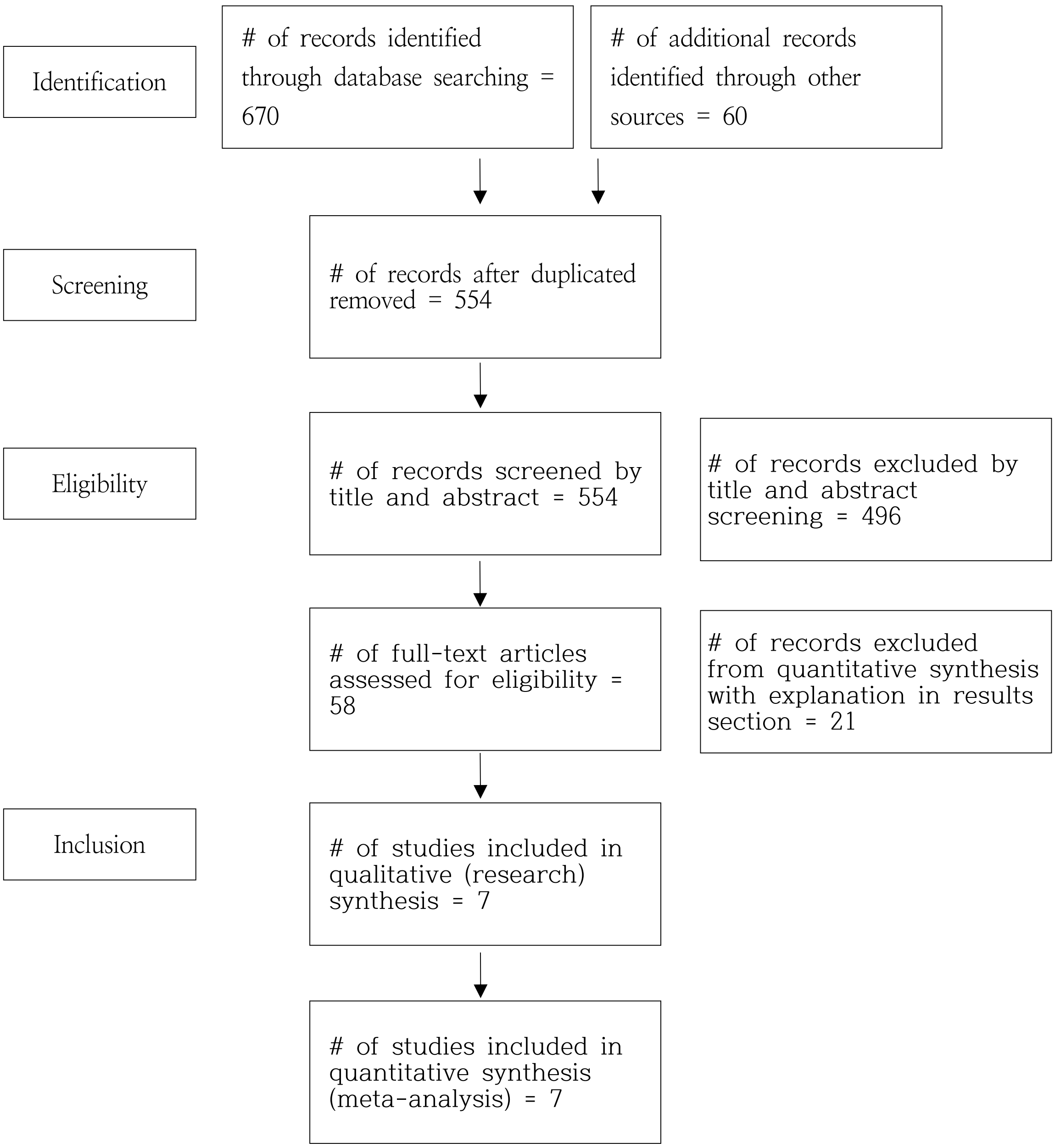

Figure. 1 Study Selection Process

Procedure

In addition to outcome data, the following data were collected: characteristics of the study participants (age, diagnosis), attrition information, treatment condition assignment

Table 1. Outcome measures

Outcome	Measure
Social Skills	Triangles, PEP-3 social reciprocity
Emotion recognition	NEPSY-II Affect recognition, Faces test, Eyes test, DANVA
Attention	NEPSY-II Auditory Attention, WebNeuro software-attention, Conners' CPT
Executive Function	Analogical reasoning task, WebNeuro software-executive function, D-KEFS
Conversational Skills	ATEC(speech, language, communication), ABAS Communication, SSPA, WebNeuro software-verbal

ABAS: Adaptive Behavior Assessment System; ATEC: Autism Treatment Evaluation Checklist; CPT: Continuous Performance Test; DANVA: Diagnostic Analysis of Non-Verbal Accuracy; D-KEFS: Dells-Kaplan Executive Functioning system; NEPSY: a developmental NEuroPSYchological Assessment; PEP: Psychoeducational Profile; SSPA: Social Skills Performance Assessment

methods (random/matched), amount of treatment (number and length of sessions), number of participants per condition, and year of publication, qualities of outcome measures (validity, reliability and rater). Outcome measures were classified into such categories as social skills, emotion recognition, attention, executive function and conversational skills (see Table 1). Analyses were conducted using a combined score if more than one measure is used for a category.

Effect Size Calculation

The effect sizes were computed using Hedge's g for each study. Hedge's g is used in order to fix biased effect size when Cohen's d is used for small sample size. Hedge's g may be interpreted similarly to Cohen's d (Cohen, 1988), with a cutoff for small (0.2), medium (0.5) and large (0.8) effects. Also, inverse variance weight is used which provides relatively stable result compare to other weighted mean effect size. The effect sizes were calculated using this formula: Hedge's g = $J\times\frac{(\overline{x_1}-\overline{x_2})}{s_{pooled}}=J\times d$, where $\overline{x_1}$ is the mean of the posttest score, $\overline{x_2}$ is the mean of pretest score, and S_p is the pooled standard deviation. J is the correction constant, $J=1-\frac{3}{4(n_1+n_2-2)-1}$. A combined effect size was computed for studies using multiple outcome measures. The overall mean effect size for studies combined was computed using a weighted formula, $\overline{ES^*}=\frac{\sum_{i=1}^{n}ES_i w^*_i}{\sum_{i=1}^{n}w^*_i}$, where w^*_i is the

Table 2. Study Characteristics

Study	Location	Mean age of sample (range)	n	Sample characteristics	VR type	Additional treatment	Design	Session Design (# of people)	No. of sessions (total time)	Outcome measured time	Primary outcome measures	Primary outcome Hedge's g	Additional outcome measures
Amaral et al. (2018)	Portugal	22 yr (16-38 yr)	15	High functioning ASD	Brain Computer Interface (VR)	None	One-group pretest-posttest	Group (2)	7 (N/R)	Last session	ATEC-speech, Language, communication	0.925	JAAT; ATEC; VABS; POMS; HADS; BDI
Didehbani et al. (2016)	US	11.4 yr (7-16 yr)	30	ASD	VR-SCT	None	One-group pretest-posttest	Group (2)	10 (10hr)	Within 2 weeks of the last session	NEPSY-II Affect Recognition	0.725	NEPSY-II response set
											Triangles	0.389	
											NEPSY-II auditory attention	0.210	
											Ekman 60	0.558	
											Analogical Reasoning Task	0.455	
Ip et al. (2018)	Hong Kong	9.03 yr (7-10 yr)	36	ASD	Cave Automatic Virtual Environment	None	Experimental group pretest-posttest (waitlist control)	Group (3~4)	28 (N/R)	Within 2 weeks of the last session	PEP-3(social reciprocity)	0.659	PEP-3; ABAS-II
											Face test	0.204	
											Eyes test	0.227	
											ABAS-communication	0.030	
Kandalaft et al. (2012)	US	21.25 yr (8-26 yr)	8	Aspergers or PDD-NOS	VR-SCT	None	One-group pretest-posttest	Individual	10 (10hr)	Within 2 weeks of the last session	Ekman 60	1.266	ACS-SP
											Eyes test	0.319	
											Triangles	1.078	
											SSPA	0.731	
Lamash et al. (2017)	Israel	14 yr (11-19 yr)	33	ASD	VAP-S Virtual Environment	Meta-cognition strategies	One-group pretest-posttest	N/R	8 (N/R)	N/R	WebNeuro software-attention	0.576	Webneuro software; BRIEF-SR; TOGSS
											WebNeuro software-executive function	0.585	
											WebNeuro software-verbal	0.377	
Stichter et al. (2013)	US	12 yr (11-14 yr)	11	ASD	iSocial-3D Virtual Learning Environment	None	Experimental group pretest-posttest (alternating programs)	Individual	5 (31-45 min each)	2 weeks after the last session	DANVA	0.440	Eyes test; The Faux Pas Stories; The Strange Stories
											D-KEFS	0.407	
											Conners CPT-II commission	0.153	
											Conners CPT-II omission	0.089	
Yang et al. (2018)	US	22.5 yr (18-31 yr)	17	High functioning ASD	VR-SCT	None	One-group pretest-posttest	Individual	N/R (10hr)	N/R	Triangles	0.460	ACS-CP

weight for each study, $w_i^* = \frac{1}{v_i + \tau^2}$. The random effects analysis was used, which assumes that the studies included are only a sample of the entire population of studies (Hwang, 2016, Chin, 2015).

Result

Seven studies published between 2009 and 2019 met criteria for inclusion with a total of 150 participants. Social skills were measured in 4 studies, and emotion recognition was measured in 4 studies, attention was measured in 3 studies, executive function was measured in 3 studies and conversational skills were measured in 4 studies. Both pre-test and post-test was demonstrated in all 7 studies, while only one study had both experimental and comparison groups. Interventions ranged in number from 8 to 28 sessions (n = 89, *Mdn* = 14.8 sessions). Hours of intervention ranged from 0.5 to 28 hours (n = 155, *Mdn* = 51.6 hours). Length of intervention ranged from 20 to 120 days (n = 337, *Mdn* = 56.1 days). Study characteristics are presented in Table 2.

The pooled effect size of VR-based interventions for 4 studies in social skills yielded a medium effect size (g = .59, *SE* = .12, 95% *CI*: .35 - .82, p < .001) (Fig. 2-1).

The pooled effect size VR-based interventions for 4 studies in emotion recognition yielded a medium effect size (g = .50, *SE* = .16, 95% *CI*: .19 - .82, p = .002) (Fig. 2-2).

The pooled effect size VR-based interventions for 3 studies in attention yielded a small effect size (g = .35, *SE* =.14, 95% *CI*: .07 - .63, p = .015) (Fig. 2-3).

The pooled effect size VR-based interventions for 3 studies in executive function yielded a medium effect size (g = .52, *SE* = .12, 95% *CI*: .28 - .77, p < .001) (Fig. 2-4).

The pooled effect size of VR-based interventions for 4 studies in conversational skills yielded a medium effect size (g = .46, *SE* = .21, 95% *CI*: .05 - .88, p = .027) (Fig. 2-5).

Publication bias

Publication bias in meta-analysis refers that published studies do not represent all the results. There is possibility that studies with positive and significant results are tend to be published more often than those with negative, non-significant results (Dickerson, 2005). It may lead a meta-analysis to overestimate the effect size of the studies. In order to detect publication bias, we used a funnel plot asymmetry test for each outcome. A funnel plot of standard error and effect size revealed some funnel plot

Study name	Outcome	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Didehbani el al., 2016	Triangles	0.402	0.217	0.047	-0.022	0.827	1.856	0.063
Ip et al., 2018	PEP-3 social reciprocity	0.674	0.187	0.035	0.307	1.041	3.599	0.000
Kandalaft el al., 2012	Triangles	1.212	0.466	0.217	0.300	2.125	2.603	0.009
Yang et al., 2018	Triangles	0.483	0.256	0.066	-0.020	0.985	1.883	0.060
		0.585	0.120	0.014	0.350	0.820	4.880	0.000

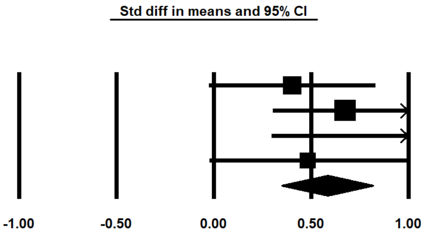

Figure 2-1. Forest plot of the VR-based intervention effect in social skills for ASD

Study name		Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Didehbani et al., 2016	NEPSY	0.749	0.226	0.051	0.305	1.193	3.310	0.001
Ip et al., 2018	Combined	0.220	0.171	0.029	-0.115	0.556	1.289	0.198
Kandalaft et al., 2012	Combined	0.892	0.439	0.192	0.032	1.751	2.033	0.042
Stichter et al., 2013	DANVA	0.476	0.318	0.101	-0.147	1.100	1.497	0.134
		0.502	0.160	0.026	0.188	0.817	3.130	0.002

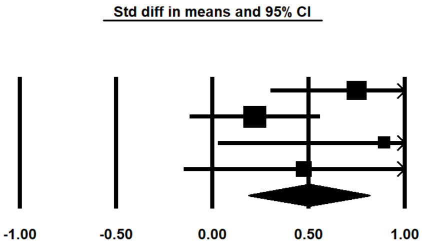

Figure 2-2. Forest plot of the VR-based intervention effect in emotion recognition for ASD

Study name	Outcome	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Didehbani el al., 2016	NEPSY	0.215	0.185	0.034	-0.147	0.577	1.166	0.244
Lamash et al., 2017	Webneuro	0.590	0.189	0.036	0.220	0.960	3.129	0.002
Stichter et al., 2013	Combined	0.131	0.303	0.092	-0.463	0.725	0.433	0.665
		0.349	0.143	0.021	0.068	0.629	2.435	0.015

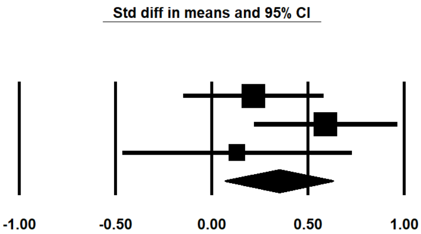

Figure 2-3. Forest plot of the VR-based intervention effect in attention for ASD

Study name	Outcome	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Didehbani et al., 2016	Analogical reasoning	0.467	0.192	0.037	0.090	0.844	2.429	0.015
Lamash et al., 2017	Webneuro	0.599	0.189	0.036	0.228	0.969	3.168	0.002
Stichter et al., 2013	Combined	0.441	0.328	0.108	-0.202	1.084	1.345	0.179
		0.521	0.125	0.016	0.276	0.765	4.176	0.000

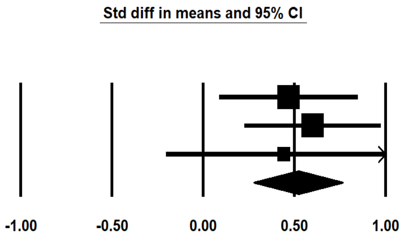

Figure 2-4. Forest plot of the VR-based intervention effect in executive function for ASD

Study name		Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Amaral et al., 2018	ATEC	0.983	0.325	0.106	0.345	1.621	3.020	0.003
Ip et al., 2018	ABAS	0.031	0.167	0.028	-0.296	0.358	0.187	0.852
Kandalaft et al., 2012	SSPA	0.822	0.409	0.167	0.021	1.624	2.010	0.044
Lamash et al., 2017	Webneuro	0.386	0.180	0.033	0.033	0.740	2.141	0.032
		0.464	0.210	0.044	0.052	0.875	2.210	0.027

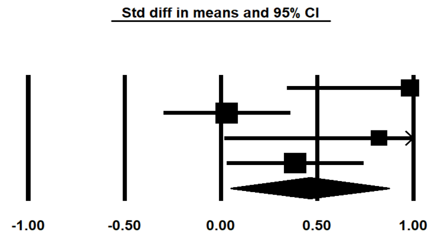

Figure 2-5. Forest plot of the VR-based intervention effect in conversational skills for ASD

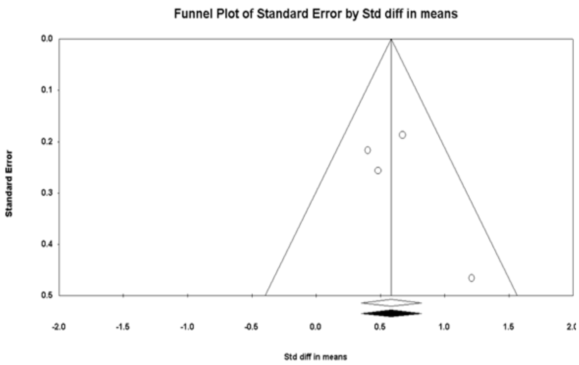

Figure 3-1. Funnel plot for estimates of VR-based intervention effect in social skills

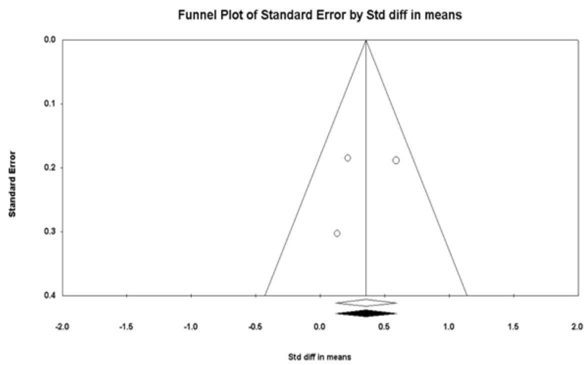

Figure 3-3. Funnel plot for estimates of VR-based intervention effect in attention

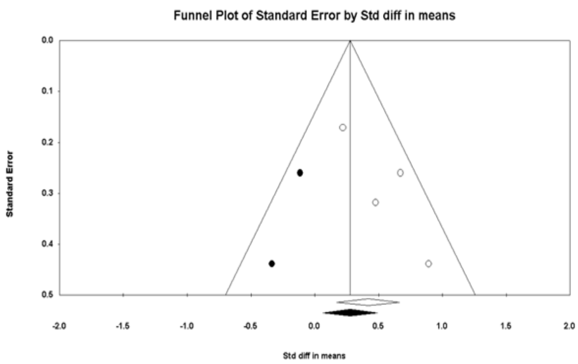

Figure 3-2. Funnel plot for estimates of VR-based intervention effect in emotion recognition

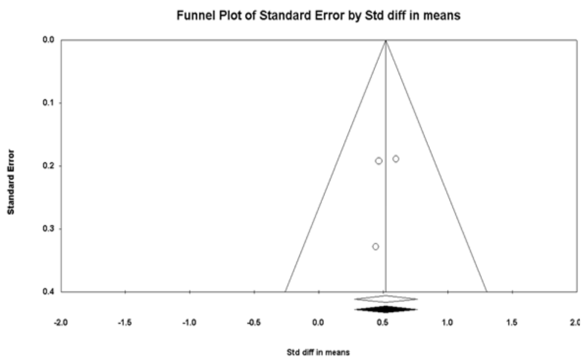

Figure 3-4. Funnel plot for estimates of VR-based intervention effect in executive function

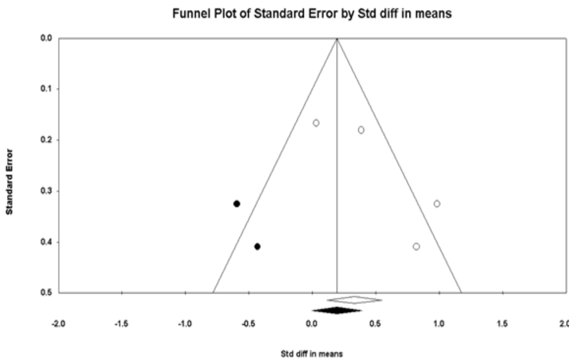

Figure 3-5. Funnel plot for estimates of VR-based intervention effect in conversational skills

asymmetry for emotion recognition and conversation skills (Figure. 3-1, 3-2, 3-3, 3-4, 3-5). The Duval and Tweedie (2000) trim and fill procedure was conducted. The filled effect sizes for emotion recognition and conversational skills were not significants: for emotion recognition (*g* = .29, 95% *CI* = -.02-.60), for conversational skills (*g* = .20, 95% *CI* = -.21-.62).

Discussion

The current meta-analysis of VR-based intervention trials (7 studies, *n* = 150) revealed that, for the developmental functions related to ASD including social skills, emotion recognition, attention executive function and conversational skills, VR-based interventions have medium effect size.

Considering publication bias, the effects were not significant for emotion recognition and conversational skills. From this sensitivity analysis, we can conservatively infer that the effects of the VR-based interventions for emotion recognition and conversational skills were not significant. However, the improvement in social skills, attention and executive function remained significant.

When there were no significant effects for emotion recognition and conversational skills, we may consider these functions are relatively inherent characteristics of ASD, which are hard to change and require a sophisticate work. According to a literature review (Danaka & Sung, 2016), emotion recognition deficits in ASD are plausibly accounted for by their avoiding the eye region. Studies showed that direct eye contact elicits a heightened physiological response. As for conversation skills, they require both social cognition and perspective taking (Dixon et al. 2009) that can not be adopted in a short period. Lack of these underlying skills may have not made enough improvement in the conversational skills despite the VR intervention.

Further, when we looked at the characteristics of subgroups that were grouped based on mean effect sizes, the effects of the VR-based interventions were different by some characteristics such as age, ASD functioning, number of sessions, country where the study conducted and additional treatment. These findings suggested factors to be considered when VR-based intervention is planned for children and young adults with ASD.

For social skills, the study by Kandalaft, et al. (2012), in which samples were diagnosed with Aspergers or PDD-NOS, showed larger effect size compared to the other three studies with the samples diagnosed with ASD or high functioning ASD. This suggests that a VR-based intervention is more effective for those with relatively normal language and intelligence than those below normal in them.

For emotion recognition, there were differences in the country where the study was conducted and the number of sessions operated. The study by Ip et al. (2018) that showed the smaller effect size was constructed with 28 sessions in Hong Kong whereas the other three studies were constructed with 5 or 10 sessions in US. This suggests that a VR-based intervention may have different effect depending on the participants' cultural and language background and can be effective with shorter sessions.

For attention and executive function, the study by Lamash et al. (2017) combined the VR-based intervention with meta-cognition strategies. The participants were introduced to meta-cognition strategies prior to the intervention. Its larger effect size suggests that combining VR intervention with teaching meta-cognitions strategies may increase the effect size than a single intervention. This finding is supported by Diamond (2013) showing that executive functioning involves attention. Also, a study showed that cortical network underlies both executive functioning and attention (Makris et al., 2007).

For conversational skills, the effect sizes were different by the participants' age. Studies by Amaral et al. (2018) and Kandalaft et al. (2012), in which the participants had the higher mean age, showed larger effect sizes than studies with younger the participants. Older participants may have experienced various situations which require conversational interactions. Our result implies that people with more experiences are better benefited by a VR-based intervention for conversational skills.

In conclusion, VR-based interventions can be considered as an acceptable treatment tool for the developmental functions of children and young adults with ASD, especially social skills, attention and executive function.

This current meta-analysis has limitations to be considered. First, this meta-analysis is limited by the limited number of studies aggregated. More studies on VR-based interventions for ASD in the future can allow calibrating the effect size. Second, this meta-analysis focused on the virtual reality. The future study can compare it with non-VR based interventions in their effectiveness. Lastly, the future study can test a moderator such as age, ASD functioning, number sessions, country where the study conducted and combined treatment, when VR-based intervention studies are sufficiently accumulated.

Finally, future studies about VRs' negative side effects for children are needed in oder to advance VR-based interventions. Several studies of VR-based interventions for adults reported that VR caused no or low side effects including sickness, oculomotor effects, disorientation, and nausea (Freeman, 2010; McMamara et al., 2018).

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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자폐스펙트럼장애에서 발달 기능을 위한 가상현실-기반 중재: 메타분석

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본 메타분석은 ASD를 가진 아동과 청년들을 위한 VR-기반 중재의 효과에 대한 연구를 집약하고 분석하였다. 2009년부터 2019년 사이에 발표된 연구 중, 사전사후 결과를 포함하고 있는 7개의 VR-기반 중재 연구가 메타분석에 포함되었다. 메타분석에 포함된 연구의 연구대상자는 총 150명이었다. 측정 결과는 ASD의 특성으로 나타나는 발달 기능인 사회적 기술, 정서인식, 주의집중, 실행기능, 의사소통기술로 분류하여 분석하였다. 무선효과모형에 따른 효과크기는 다음과 같이 나타났다: 사회적 기술(g = .59, SE = .12, 95% CI: .35-.82), 정서인식(g = .50, SE =.16, 95% CI: .19-.82), 주의집중(g = .35, SE = .14, 95% CI:.07-.63), 실행기능(g = .52, SE = .12, 95% CI:.28-.77), 의사소통기술(g = .46, SE = .21, 95% CI: .05-.88). VR-기반 중재의 효과가 대체로 중간이며, 주의집중에 대한 효과크기는 상대적으로 작았다. ASD에 대한 VR-기반 중재의 효과와 관련하여 연령, ASD 기능 수준, 연구가 이루어진 국가, 중재 회기 수 및 VR-기반 중재와 함께 제공된 추가 치료개입 등 중재의 효과에 영향을 미칠 수 있는 여러 환경 요인을 논의하였다.

주요어 : 자폐스펙트럼장애, 가상현실, 사회적기술, 정서인식, 주의집중, 실행기능, 의사소통기술