Review Article

Effects of Virtual Reality Program on Glycated Hemoglobin, Static and Dynamic Balancing Ability, and Falls Efficacy for Diabetic Patients: A Systematic Review and Meta-Analysis

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Purpose: We aimed to confirm the effects of virtual reality programs used for patients with diabetes on reducing blood glucose levels and improving physical function. **Methods:** In this systematic literature review and meta-analysis, literature was collected from various databases for randomized controlled trials published in Korean, Chinese, and English by May 2021. The search yielded 1,243 studies. Eight studies were selected for the systematic literature review, and six studies were included in the meta-analysis. **Results:** In the eight selected studies, a non-immersive virtual reality programs were employed as the intervention method. The effect size of the virtual reality programs on glycated hemoglobin (HbA1c) was -0.40, with no significant difference between experimental and control groups. The effect size on static balancing ability was 1.04, and the effect size on dynamic balancing ability was 2.39. The effect size on falls efficacy was 0.69, and all functional outcomes differed significantly between the experimental and control groups ($p < .05$). A subgroup analysis of static balancing ability was performed according to the duration of the interventional virtual reality program. When the virtual reality programs lasting for more than six weeks, shows an effect size of 1.27 for static balance ability, which was statistically significant (Z=3.32, $p < .001$). **Conclusion:** Virtual reality programs for participants with diabetes did not reduce HbA1c, but improved balance ability and falls prevention efficacy. The virtual reality program is an effective method for diabetics to be interested and consistently self-care.

Key Words: Diabetes mellitus; Meta-analysis; Systematic review; Virtual reality

INTRODUCTION

The global prevalence of diabetes is increasing; the International Diabetes Federation has reported that 537 million people of total population in 2021, and 643 million people are predicted to become diabetic by 2030[1]. Diabetes mellitus severely damages the heart, blood vessels, eyes, kidneys, and nerves, and causes loss of balance [2], an increased risk of falls [3], reduced quality of life [4], and mortality; hence, the importance of diabetes prevention and management is constantly being emphasized in our society [5].

Patients must continuously perform self-care, which includes understanding diabetes, performing blood sugar tests, following a strict diet, and performing exercises, in addition to medications, to effectively manage the disease [6]. Approaches to encourage patients with diabetes to implement effective self-care regimens include telephone counseling programs [7], individual diabetes education [8], resistance exercise programs [9], mobile applications [10], and diabetes camps [11]. However, it is often difficult to engage participants continuously and maintain their interest throughout intervention programs. To maintain participants' interest, virtual reality programs with more engaging features have been introduced [12]. A study using virtual reality [13] has been conducted recently.

Virtual reality technology uses a computer-generated environment to immerse people/users in a perception of reality [14]. There are two types of virtual reality currently in use: immersive virtual reality, which uses a head-mounted display for an immersive experience and non-immersive virtual reality, which uses a 3D graphics environment as seen on console game systems and motion capture cameras [15]. Virtual reality programs have high educational influence and create an immersive experience and increase the concentration of users with their strong simulation; hence, they effectively motivate the desire to win and help sustain interest [16]. In addition, they enable continuous education and training [17], providing a safe experience [18]. Therefore, using virtual reality programs that provide patients with diabetes an opportunity to educate themselves and perform effective self-care can help control their blood sugar levels and improve exercise function.

Virtual reality programs are provided through various methods such as Kinect [19], Nintendo Wii [20], immersive virtual reality environment [21,22], wearable sensor and real time visual feedback [23]. These programs have shown a significant decrease in hemoglobin A1c (HbA1c) levels [19,20], and a significant increase in body function

[23] and physical activity [21,22] for individuals with diabetes. Therefore, virtual reality is a suitable treatment method for controlling blood sugar levels and improving physical function in individuals with diabetes. Based on these studies, several systematic literature reviews and meta-analyses on the effects of virtual reality programs and games for patients with diabetes were conducted, and the findings corroborated that games and virtual reality programs were effective in motivating healthy behaviors [24], resulting in positive effects on the quality of life, body balance, and muscle strength; however, they had no effect on diabetes-related knowledge or HbA1c levels [25]. But both the aforementioned systematic literature reviews and meta-analyses [24,25] were based on literature up to 2014, with study designs including randomized controlled trials (RCTs) and non-randomized experimental trials, and preliminary studies [24]. Interventions included virtual reality programs and games [24,25]. However, virtual reality is different from mobile or online games in terms of the virtual world, immersive experience, feedback, and interaction [26]; therefore, conducting a systematic literature review and meta-analysis of studies that used virtual reality programs only as interventions, is necessary. This study aims to provide fundamental data for scientific research through systematic review and meta-analysis of the effects of virtual reality programs on patients with diabetes. The study participants were limited to patients with diabetes, and immersive and non-immersive virtual reality programs were applied as interventions, while the control group was the absence of a virtual reality program. The outcome variables were chosen to include various factors, including changes in blood glucose levels, so all possible outcome variables were considered in the paper. Randomized controlled trials studies published up to May 2021 were searched.

The purpose of this study is to systematically review the general characteristics (author, country, intervention group, participants, sample size, and so on) of previous studies that have evaluated the effects of virtual reality programs for patients with diabetes and to analyze the effects (HbA1c levels, static balance, dynamic balance, falls efficacy) of virtual reality programs by presenting the effect size of the intervention through a meta-analysis.

METHODS

1. Study Design

This study is a systematic literature review and meta-analysis of RCTs that synthesized qualitative and quanti-

tative data to confirm the effects of virtual reality programs utilized for patients with diabetes. The research plan for this study was registered in PROSPERO (https://www.crd.york.ac.uk/PROSPERO/) and the registration number (CRD42021236581) was obtained on March 12, 2021. Initially, the outcome variable was only HbA1c; however, upon reviewing the literature and discovering that virtual reality had a significant effect on physical function [A1,A2,A5-A7], the study was modified and re-approved by PROSPERO on July 5, 2022.

2. Literature Selection Criteria

Specific questions for the systematic literature review, pertaining to PICOS (Participants, intervention, comparison, outcome, and study design) are as follows. Participants of these studies included patients with prediabetes, type 1 or type 2 diabetes, or gestational diabetes. The experimental intervention was a virtual reality program applied to patients with diabetes; hence, all studies using immersive virtual reality with a head-mounted display or non-immersive virtual reality with Nintendo Wii, EyeToy, Xbox, Kinect, and PlayStation were included. Comparative interventions were those that provide only routine care such as exercise and education, and periodic hospital visits that did not involve virtual reality programs. HbA1c level, static and dynamic balance, and falls efficacy were examined to validate the effect of the virtual reality programs. Study design was RCTs. The exclusion criteria were as follows: (1) studies on animals or preclinical trials; (2) studies including patients without diabetes; (3) studies whose original text could be verified; (4) studies not published in Korean, English, or Chinese; (5) non-experimental studies such as reviews or observations; and (6) unpublished theses.

3. Literature Search

For literature search and analysis, studies up to May 2021 were investigated. English databases such as PubMed, EMBASE, CINAHL, Cochrane Central Register of Controlled Trials (CENTRAL), and MEDLINE, Chinese databases such as China National Knowledge Infrastructure (CNKI), Wanfang, and VIP Information, and Korean databases such as DBpia, Korean Studies Information Service System (KISS), Research Information Sharing System (RISS), and Science on were used to search for published articles or theses. In order to increase the sensitivity of literature search, gray literature such as dissertations, news, and presentation materials were manually searched. In

Korean databases, search terms including "diabetes (당뇨)," "gestational diabetes (임신성 당뇨)," "prediabetes (전단계 당뇨)," "type 1 diabetes (1형 당뇨)," "type 2 diabetes (2형 당뇨)," "virtual reality (가상현실)," "Wii," "EyeToy," "Xbox," "Kinect," "PlayStation," and "Nintendo" were used (Appendix 1-A). For an efficient search in English databases, MeSH terminology, Boolean operator, and truncation were used. MeSH and text words used in the combination of P (patient) AND I (intervention) AND O (outcome) were as follows: search terms for P (patient) included "DM," "Diabetic," "Diabetes," "GDM," "Type 1 DM," "Type 2 DM," "Prediabetic," "Diabetes, Gestational [MeSH]," "Diabetes Mellitus [MeSH]," "Diabetes Mellitus, Type 1[MeSH]," "Diabetes Mellitus, Type 2[MeSH]," and "Prediabetic State [MeSH]"; search terms for I (intervention) included control or text words such as "Virtual Reality [MeSH]," "Wii," "EyeToy," "Xbox," "Kinect," "PlayStation," and "Nintendo." No specific restrictions were set for search terms for O (outcome) (Appendix 1-B). In Chinese databases, search terms such as "Diabetes (糖尿病)," "Diabetes* (糖尿*)," "Virtual Reality (虚拟现实)," "Virtual Reality (假想现实)," "Remote Reality (远程现实)," "Human-Computer Interaction (人机互动)," "Videogame (视频游戏)," "Somatosensory Game (体感游戏)," "Wii," "EyeToy," "Xbox," "Kinect," "PlayStation," and "Nintendo" were used (Appendix 1-C). For the selected literature, the search results were deduplicated. The titles and abstracts were independently reviewed by three researchers: a professor of nursing, a doctor of nursing, and a doctor of Chinese medicine, according to the PICOS and exclusion criteria, for primary selection of studies. Then, secondary selection involved reviewing the full texts of the remaining studies to identify studies to be included based on the inclusion and exclusion criteria. The Chinese literature search and translation were assisted by a Chinese doctoral student in oriental medicine. Any disagreement between the authors pertaining to the selection process was resolved through sufficient discussion, and the opinion of a third author, from the field of oriental medicine, was considered.

4. Qualitative Assessment of Literature

To evaluate the quality of literature used in this study, Risk of Bias the Cochrane risk-of-bias tool (RoB) was used [27], and the analysis was conducted using the Cochrane RevMan Web.

5. Data Analysis

After analyzing the characteristics of studies included

in the systematic literature review, data such as First Author, Country, Participants, Age, Sample size, Intervention group, Control group, Main outcome measures, Results, and Author's conclusion were extracted. In a meta-analysis, the random effects model was used, since there was a substantial difference between the selected studies [28]. The effect size was analyzed by a standardized mean difference (SMD), mean difference (MD) and Cohen's d. The effect of the outcome variable in this study and the 95% confidence interval (CI) were analyzed using inverse-variance. The effect size was classified as small (effect size of 0.2 or less), medium (effect size of 0.5), and large (effect size of 0.8 or more) [29]. In order to confirm heterogeneity, the forest plot was checked, and the heterogeneity between studies was analyzed using Higgins' I^2 statistic. The I^2 value of $\leq 25.0\%$, 25.0~75.0%, and >75.0% was assessed as "low," "medium," and "high" "heterogeneity," respectively [30].

RESULTS

1. Characteristics of Studies Included in the Systematic Literature Review

The Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) were used to describe the status of the step-by-step literature selection process of this study in an easy-to-read and detailed manner [31]. In the database, 1,243 articles were searched. After excluding 171 duplicates, 1044 studies were excluded according to the PICOS and exclusion criteria. After the full texts of articles were reviewed, eight studies were finally selected. Qualitative analysis was performed on the eight selected studies, and the results of six of these studies were included in the meta-analysis (Figure 1).

All eight studies were journal articles and were published in 2010 or later. Three studies were conducted in the United States [A5-A7], four studies were conducted in Asia [A1,A2,A3,A8], two studies in South Korea [A1,A2], two studies in China [A3,A8], and one study was conducted in Germany [A4]. In terms of the study participants, there were seven studies on type 2 diabetes [A1-A6, A8] and one study on prediabetes [A7]. Two of the studies on type 2 diabetes involved participants who were patients with a complication of diabetic neuropathy [A5]. In terms of age, six studies included participants aged ≥ 60 years [A1,A2,A4-A6,A8], and two studies included participants aged 34-55 years [A3,A7]. Regarding the type of virtual reality used, none of the studies used immersive virtual reality programs using head-mounted displays. All

eight studies were non-immersive virtual reality program studies using 3D stereoscopic images, gaming consoles, motion capture cameras, and body-tracking sensors. Regarding the methods for executing the virtual reality programs, two studies used PlayStation and EyeToy [A1,A2], three studies used Nintendo Wii [A4,A6,A7], one study used sensor-based interactive exercise training [A5], and two studies used Kinect [A3,A8]. In terms of years and countries where certain virtual reality programs were used, PlayStation and EyeToy were used in South Korea in 2012 [A1] and 2013 [A2]. Nintendo Wii was used in Germany in 2013 [A4] and in the US in 2018 [A6] and 2019 [A7]. Sensor-based interactive exercise training was used in the US in 2015 [A5], and Kinetic was used in China in 2015 [A3] and 2020 [A8]. The application time for the virtual reality program was 30 min in two studies [A3,A4]; 35 min, five times a week in one study [A8]; 40 min, three times a week in one study [A6]; 45 min, twice a week in one study [A5]; and 50 min, twice a week in two studies [A1,A2]; and 50 min, three times a week in one study [A7]. The duration of the virtual reality intervention was 15 days in one study [A3]; four weeks in one study [A5]; six weeks in one study [A8]; 10 weeks in two studies [A1,A2]; and 12 weeks in three studies [A4,A6,A7]. The minimum number of samples in each experimental and control group ranged from 14~93, and the total number of samples ranged from 30~176. The control group received routine treatment in two studies [A4,A5]; diabetes education in two studies [A1,A2]; routine treatment and diabetes education in one study [A3]; routine treatment in one group and general exercise in one group, with two control groups in one study [A7]; general exercise in one study [A6]; and rehabilitation treatment and balance training in one study [A8]. The main outcome variables of this review were HbA1c, static body balance, dynamic body balance, and falls efficacy. Among the eight studies included in the qualitative analysis, three studies measured HbA1c levels as an outcome variable [A3,A4,A7], five studies measured static body balance [A1,A2,A5,A6,A8], two studies measured dynamic body balance [A2,A8], and two studies measured falls efficacy [A2,A5]. Regarding the effect of the application of virtual reality programs for patients with diabetes, HbA1c level was used to measure blood glucose control. Among body balance scales, static balance scales included the Postural Sway and One-Leg Standing tests, and dynamic balance scales included the Berg Balance Scale. The falls efficacy scales included the Falls Efficacy Scale-International (FES-I) and the Modified Falls Efficacy Scale (MFES) (Table 1).
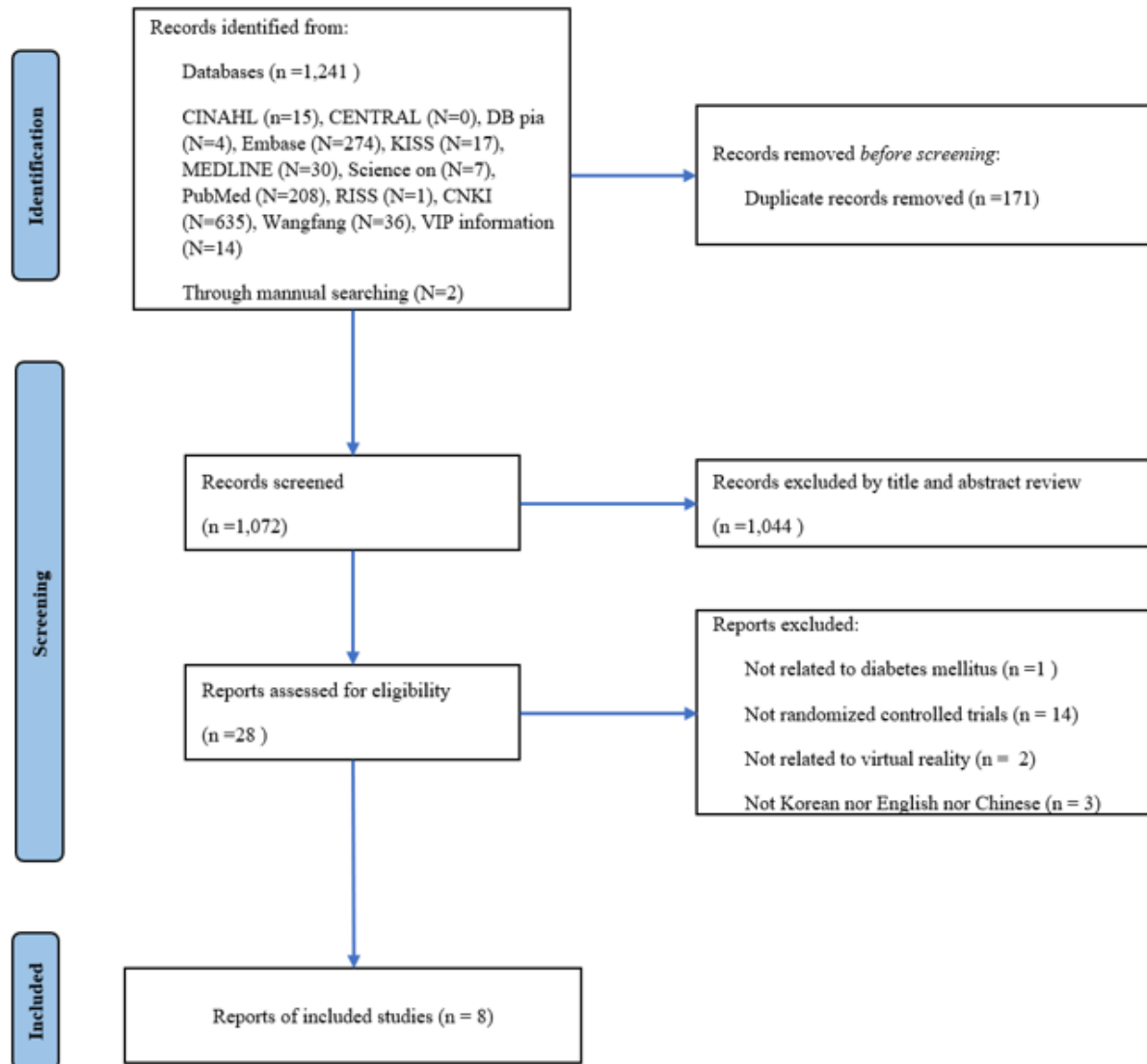
CENTRAL=Cochrane Central Register of Controlled Trials; CNKI=China National Knowledge Infrastructure; KISS=Korean Studies Information Service System; RISS=Research Information Sharing System; DM=Diabetes mellitus; RCT=Randomized controlled trials.

Figure 1. Flow chart of study selection process.

2. Qualitative Assessment of Literature

The results after entering the eight selected studies into the RevMan software, according to the quality evaluation criteria are as follows (Figure 2). In terms of bias arising from the randomization process, the RoB was evaluated as "low" in two studies; the allocation sequence was random and concealed until participants were enrolled and assigned to interventions. Six studies were evaluated as "unclear," since there was no mention of allocation concealment. In terms of bias due to deviations from intended interventions, the RoB was evaluated as "low," in two studies while the remaining six studies did not mention blind-

ing of caregivers and people delivering the intervention, and the RoB was evaluated as "unclear." As a result of analyzing bias due to missing data, one study had a "high" RoB since the dropout rate of 54.0% in experimental group. In the bias in measurement of the outcome, seven studies were evaluated as "unclear," since there was no mention of blinding of the outcome evaluation. In terms of bias in selection of the reported result, two studies had a "high" RoB since the results were incomplete and could not be used for meta-analysis. In the remaining six studies, the RoB was assessed as "unclear" since the trial registration number was not included.

Table 1. Summary of the Virtual Reality Programs' Effects on HbA1c Levels, Balance, and Falls Efficacy in Patients with Diabetes

No	First author (year)/ Country	Participants Age (year)/ Mean or range	Intervention group Intervention Method	Control group	Main outcome measures	Results	Author's conclusion
A1	Lee (2012)[†] South Korea	Type 2 DM (A) 73.8 (B) 74.3	(A) PlayStation, EyeToy (50 min twice a week for 10 weeks) + Health education (N=27)	(B) Health education (N=28)	Static balance (postural sway)	MD -20.28 95% CI: [-25.51, -15.05]	"The virtual reality-based program···an effective intervention for improving the balance of the elderly with diabetes···"
A2	Lee (2013)[†] South Korea	Type 2 DM (A) 73.78 (B) 74.29	(A) PlayStation, EyeToy (50 min twice a week for 10 weeks) + Health education (N=27)	(B) Health education (N=28)	Dynamic balance (BBS) Falls efficacy (MFES) Static balance (one-leg standing)	MD 2.27 95% CI: [1.00, 3.54] MD 1.08 95% CI: [0.45, 1.71] MD 5.80 95% CI: [1.99, 9.61]	"The virtual reality exercise program can be used to reduce the risk of falls in elderly individuals with diabetes"
A3	Deng (2015)[†] China	Type 2 DM (A) 35~55 (B) 34~54	(A) Kinetic (30 min/day for 15 days) + Usual care + Health education (N=30)	(B) Usual care + Health education (N=30)	HbA1c	MD -0.90 95% CI: [-1.09, -0.71]	"Strengthening diabetes exercises combined with somatosensory tracking device Kinect··· is beneficial to reduce HbA1c..."
A4	Kempf (2013)[†] Germany	Type 2 DM (A) 61 (B) 60	(A) Wii Fit Plus (at least 30 min/day for 12 weeks) + Routine care (N=93)	(B) Routine care (N=83)	HbA1c	MD 0.10 95% CI: [-0.14, 0.34]	"Wii fit plus was able to motivate T2DM patients to improve glucometabolic control···"
A5	Grewal (2015)[†] USA	Type 2 DM + DPN (A) 62.58 (B) 64.9	(A) Sensor-based interactive balance training (45 min training session, twice a week for 4 weeks) + Standard of care (N=18)	(B) Standard of care (N=16)	Static balance (postural sway) Falls efficacy (FES-I)	MD -0.48 95% CI: [-1.45, 0.49] MD -4.53 95% CI: [-11.86, 2.80]	"···exercise training through an interactive virtual interface with real-time visual feedback··· significantly improve postural balance in people with diabetic peripheral neuropathy··· may reduce the risk of fall."
A6	Morrison (2018) USA	Type 2 DM (A) 66.1 (B) 67.8	(A) Wii Fit Balance Board (40 min, thrice a week for 12 weeks) (N=14)	(B) Supervised training (N=32)	Static balance (postural sway)	(A) Positive change significantly ($p<.05$) (B) Positive change significantly ($p<.05$)	"Both 12 weeks of supervised balance training and unsupervised, at home balance activity (using the Nintendo Wii Fit)... reduces falls risk in older T2DM individuals."
A7	Bock (2019) USA	Prediabetics (A) 49.3 (B) 52.3 (C) 52.0	(A) Wii Fit plus (50 min, thrice a week for 12 weeks) (N=27)	(B) Treadmill, cycling (50 min, thrice a week for 12 weeks) (N=28) (C) Mailing on general health topic (N=29)	HbA1c	(A, B) $p<.05$ (B, C) NS (A, C) $p<.05$	"Exercise videogames···improve management of blood glucose..."
A8	Zeng (2020)[†] China	Type 2 DM + DPN (A) 63.40 (B) 64.67	(A) Doctor Kinetic (35 min/day, 5 times/week) + Routine care + Integrative rehabilitation + Conventional rehabilitation (35 min/day, 5 times/week) for 6 weeks (N=15)	(B) Routine care + Integrative rehabilitation + Conventional rehabilitation (35 min/day, 5 times/week) for 6 weeks (N=15)	Dynamic balance (BBS) Static balance (postural sway)	MD 2.80 95% CI: [0.48,5.12] MD -0.24 95% CI: [-0.40, -0.08]	"Virtual sports games can effectively improve the static and dynamic balance function of elderly DPN patients···"

BBS=Berg Balance Scale; CI=confidence interval; DM=diabetes mellitus; DPN=diabetic peripheral neuropathy; FES-I=Falls Efficacy Scale-International; MD=mean difference; MFES=Modified Falls Efficacy Scale; NR=not reported; NS=not significant; [†]Studies included in the meta-analysis.
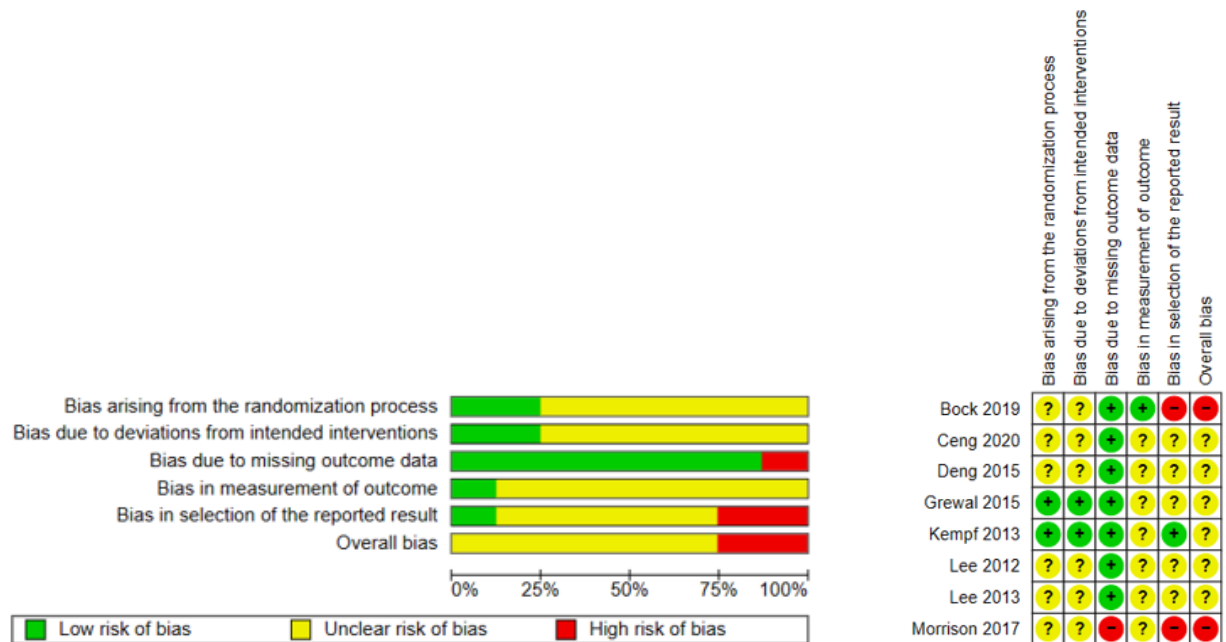
A. Review author's judgements about risk of bias item presented as percentage for included studies.

B. Review author's judgement about risk of bias item for each included study.

Figure 2. Risk of bias for selected studies.

3. Effect Size of Virtual Reality Program Applied for Patients with Diabetes on HbA1c Levels

The effect size of the experimental group with the virtual reality program applied and the control group without the virtual reality program applied was -0.40 (n=236, 95% CI: -1.38~0.58), which was not statistically significant (Z=0.81, p=.42). The heterogeneity between studies was high with Higgins' I^2=98.0% (Figure 3-A).

4. Effect Size of Virtual Reality Program Applied to Diabetics on Balance Ability

1) Static balance

Postural sway and one-leg standing test were used to measure static balance. Since the two scales oppose each other, they were adjusted using a minus sign. The effect size of the experimental group with the virtual reality program applied and the control group without the virtual reality program applied was 1.04 (n=174, 95% CI: 0.35~1.73), which was statistically significant (Z=2.95, p=.003). However, a subgroup analysis was performed due to the high heterogeneity among studies with Higgins I^2=77.0%. This analysis was conducted by dividing the period of application of the virtual reality program into two groups; one to five weeks and more than six weeks. The experimental

group that participated in the virtual reality program from one to five weeks demonstrated an increase of 0.33 (n=34, 95% CI: -0.35~1.00) in static balance when compared to the control group, with no statistically significant difference (Z=0.94, p=.35). The experimental group for which the virtual reality program was applied for more than six weeks demonstrated an increase of 1.27 (n=140, 95% CI: 0.52~2.02) when compared to the control group, with a statistically significant difference (Z=3.32, p<.001) (Figure 3-B).
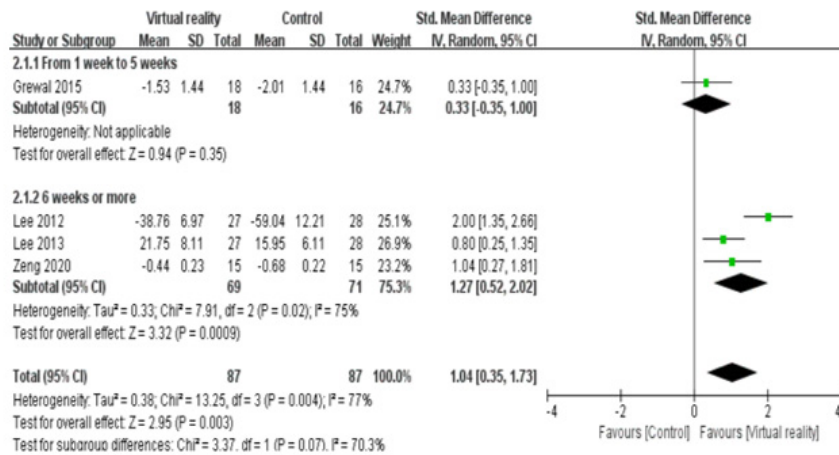
2) Dynamic balance

The effect size comparing the experimental group with the virtual reality program applied and the control group without it being applied was 2.39 (n=85, 95% CI: 1.28~3.51) and was statistically significant (Z=4.21, p<.001). The heterogeneity between studies was low, with Higgins' I^2=0.0% (Figure 3-C).

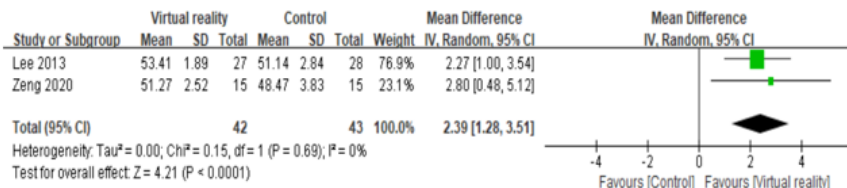## 5. Effect Size of Virtual Reality Program Applied for Patients with Diabetes on Falls Efficacy

The methods for measuring falls efficacy in this study included the FES-I and the MFES. Since the two scales opposed each other, they were adjusted using a minus sign. The effect size of the experimental group with the virtual reality program applied and the control group without it
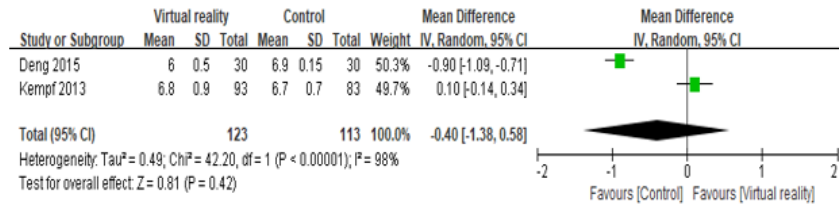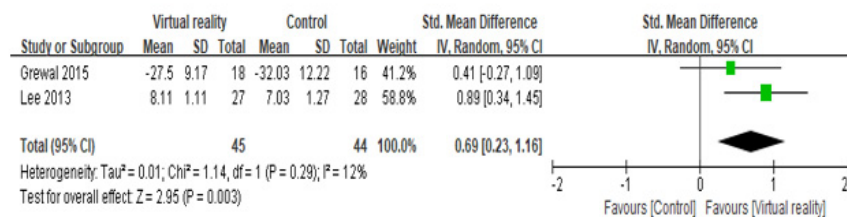
A. The effect of virtual reality program for HbA1c levels.

B. The effect of virtual reality program for static balance.

C. The effect of virtual reality program for dynamic balance.

D. The effect of virtual reality program for falls efficacy.

Figure 3. Forest plot of the effect of virtual reality programs on diabetes.

being applied was 0.69 (n=89, 95% CI: 0.23~1.16), which was statistically significant (Z=2.95, $p=.003$). The heterogeneity between studies was low, with Higgins' I^2=12.0% (Figure 3-D).

The asymmetry of the funnel plot could not be confirmed. According to Higgins, this test required at least ten studies to be included in the analysis [32].

DISCUSSION

This systematic literature review and meta-analysis was conducted to confirm the methodology and effect of the virtual reality program for patients with diabetes. Eight studies were included based on the selection criteria and were qualitatively analyzed, and six studies were included in the meta-analysis.

These eight studies had a low risk of missing outcome data. The randomization process, deviations from intended interventions, measurement of the outcome, and selection of the reported results were not described in the literature; hence, identifying the risk of these biases was difficult. In future RCTs, randomization and blinding should be strictly designed to avoid investigator bias, and this information should be well-elucidated in the literature. Additionally, the registration number of the clinical trial and related information should be provided to identify potential bias.

Qualitative analysis of all eight studies used non-immersive virtual reality interventions. Although immersive virtual reality programs have a higher immersive experience, studies that applied them were limited since the development of such programs were challenging. An immersive virtual reality program was applied only in one non-randomized experimental study, which included exercise, education, and treatment for patients with diabetes [13]. Therefore, conducting a randomized trial, for patients with diabetics in the future is necessary to confirm the effect of this program.

HbA1c were analyzed to confirm the effect of the virtual reality program on the blood sugar control of patients with diabetes. HbA1c level were decreased in the experimental group when compared to the control group, although it was not statistically significant. In a previous systematic literature review [25], reduction in HbA1c levels was not observed when games and virtual reality programs were employed. Earlier studies could not validate the effect of virtual reality programs on HbA1c levels, though two studies included game interventions [33,34]. In the study that employed an immersive virtual reality program for 12 weeks [13], a study that administered a 12-week program using Kinect [19], and a study that administered a 12-week program using Nintendo Wii [20], HbA1c levels were significantly reduced due to the experimental intervention; however, these were non-randomized trials. Therefore, in order to confirm the effect of the virtual reality program on HbA1c levels, strict experimental studies will be needed in the future. In addition, education on medical treatment for diabetes, lifestyle improvement, diet, and exercise therapy are important for diabetes management [35]. Since virtual reality programs, including diabetes education, are reportedly effective in reducing HbA1c levels [13], it is necessary to develop these modalities.

Static and dynamic balances, and falls efficacy were analyzed to confirm the effect of the virtual reality program on the physical ability of patients with diabetes. In a study that provided a virtual reality exercise program for five weeks, the experimental group demonstrated no significant difference when compared to the control group [A5]. In other studies, significant improvements in static balance indicated that virtual reality exercise programs should be provided for more than six weeks [A1,A2,A8]. Previous studies that employed vibration stimulation resistance exercise [36], resistance exercise using a sling [37], and aqua therapy [38] reported significant improvement of balance after a six-week or longer exercise intervention. Thus, virtual reality exercise programs should be designed as a six-week or longer program to enhance balance.

This study is significant because it confirms the effect of virtual reality programs for patients with diabetics who needed continuous management by systematically reviewing the research that applied these programs. Conversely, an insufficient number of randomized controlled experimental studies applying virtual reality programs, which made presenting sufficient evidence difficult, is a limitation of this study.

CONCLUSION

The findings indicated that the effect of virtual reality programs in reducing HbA1c levels could not be confirmed; however, it was effective in improving balance ability and falls efficacy. Based on these results, we recommend the following. Subsequent studies should develop virtual reality programs not only for exercise but also for education about diabetes mellitus to promote effective management of diabetes mellitus. Further, these programs should be designed to be at least six weeks to improve physical functioning of individuals with diabetes mellitus. In the future, strictly randomized and blinded studies are necessary, and a repeat systematic review and meta-analysis is recommended after the accumulation of such studies.

CONFLICTS OF INTEREST
The authors declared no conflict of interest.

AUTHORSHIP
Study conception and design acquisition - Yim Y-R and Hur M-H; Data collection - Yim Y-R and Hur M-H; Data analysis & Interpretation - Yim Y-R and Hur M-H; Drafting & Revision of the manuscript - Yim Y-R and Hur M-H.

DATA AVAILABILITY
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Appendix 1. Search Strategy

A. Korean

No	Search term	No.	Search term
1	DM	9	Eyetoy
2	Gestational diabetes	10	Xbox
3	Prediabetes	11	Kinect
4	Type 1 DM	12	Playstation
5	Type 2 DM	13	Nintendo
6	1 OR 2 OR 3 OR 4 OR 5	14	7 OR 8 OR 9 OR 10 OR 11 OR 12 OR 13
7	Virtual Reality	15	6 AND 14
8	Wii		

B. English

No	Search term	No	Search term
1	DM	12	Prediabetic state [MeSH]
2	Diabetic	13	1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8 OR 9 OR 10 OR 11 OR 12
3	Diabetes	14	Virtual reality [MeSH]
4	GDM	15	Wii
5	Type 1 DM	16	Eyetoy
6	Type 2 DM	17	Xbox
7	Prediabetic	18	Kinect
8	Diabetes, gestational [MeSH]	19	Playstation
9	Diabetes mellitus [MeSH]	20	Nintendo
10	Diabetes mellitus, Type 1 [MeSH]	21	14 OR 15 OR 16 OR 17 OR 18 OR 19 OR 20
11	Diabetes mellitus, Type 2 [MeSH]	22	13 AND 21

C. Chinese

No	Search term	No	Search term
1	Diabetes (糖尿病)	10	Wii
2	Diabetes* (糖尿*)	11	Eyetoy
3	1 OR 2	12	Xbox
4	Virtual reality (虚拟现实)	13	Kinect
5	Virtual reality (假想现实)	14	Playstation
6	Remote reality (远程现实)	15	Nintendo
7	Human-computer interaction (人机互动)	16	4 OR 5 OR 6 OR 7 OR 8 OR 9 OR 10 OR 11 OR 12 OR 13 OR 14 OR 15
8	Videogame (视频游戏)	17	3 AND 16
9	Somatosensory game (体感游戏)		

Appendix 2. List of the included studies

A1. Lee SW, Song CH. Virtual reality exercise improves balance of elderly persons with type 2 diabetes: a randomized controlled trial. Journal of Physical Therapy science. 2012;24(3):261-265. https://doi.org/10.1589/jpts.24.261

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