Effectiveness of Virtual Reality Training in Improving Knowledge among Nursing Students:

A systematic review, meta-analysis and meta-regression

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Introduction

Knowledge is a core component of nursing competency. Teaching methods which allow students to gather, synthesize and apply knowledge correctly, and provide competent care upon graduation is essential. Virtual reality (VR) provides a safe environment, where knowledge can be meaningfully applied in a simulated three-dimensional environment as demonstrated by the experiential learning theory by Kolb (1984). Numerous reviews have supported VR training. However these reviews are limited by the use of a few databases, high heterogeneity, mixed research design, population mixture, inconsistent outcomes and involvement of narrative synthesis only, with limited statistical analysis. The objectives of this systematic review and meta-analysis were to (1) examine the effectiveness of VR training in improving knowledge of nursing students and (2) identify essential elements in designing VR training.

Methods

This review was registered in the PROSPERO database at the Centre of Reviews and Dissemination in the United Kingdom.

Randomised controlled trials (RCTs), not limited by publication year, that involved VR training for nursing students in pre- and post-registration programmes, compared against conventional training methods, with knowledge as an outcome measure were included. A comprehensive three-step search strategy was conducted across published literature, ongoing trials and targeted journals. Study selection was conducted by two independent reviewers with inter-investigator agreement determined by Kappa statistic > 0.6. Different responses were referred to a third reviewer until consensus is reached.

Data was extracted using a standardised data extraction form. The authors of the selected trials were contacted to obtain additional or clarify information. The risk of bias tool and the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) system were employed to assess individual and overall quality of evidence, respectively. Publication bias was evaluated using funnel plot asymmetry and Egger's test.

Meta-analysis and random-effects meta-regression was performed using the Comprehensive Meta-analysis 3.0 software. The overall effect was measured using Hedges' *g* and determined using Z-statistics at the significance level of $p<0.05$ Heterogeneity was assessed using χ^2 and I^2 statistics, p<0.10 indicates the presence of significant statistical heterogeneity. Sensitivity and subgroup analyses were employed to reduced overall heterogeneity across studies ($I^2 > 40\%$), and compared the treatment effects amongst intervention features.

Results

The study selection process was conducted according to PRISMA guidelines, illustrated in Figure 1. A total of 14 RCTs were included in the analysis involving 975 participants from 2007 to 2019 across eight countries. Details of VR training was differentiated based on immersion level, length and duration of VR training, mode of delivery and facilitation. Figure 2 illustrates the pooled meta-analysis results from the 14 RCTs, which examined knowledge scores between VR and control group. There is significantly higher knowledge scores (SMD 0.48, 95%CI 0.13-0.84) were found in the VR group compared to the control group (Z=2.66, *p*=0.01) with a small-to-medium effect (*g*=0.47) using the random effects model. Considerable heterogeneity (I^2=85%, *p*<0.01) was revealed among the 14 trials. Sensitivity analysis and subgroup analyses were attempted to resolve heterogeneity, but remains significant (I^2>40%).

Subgroup analysis was performed to provide recommendations for VR design as illustrated in Table 1. A random effects meta-regression revealed that covariates (i.e. year of publication, age of participants, country, students, content, immersion level, provider, platform, duration and number of session) had no effect on knowledge scores (*p*>0.05).

There was high prevalence of unclear (38.1%) and high (19%) risks of bias within studies across the six domains observed. The overall quality of evidence is graded as very low using the GRADE certainty assessment due to downgrades in the domains of risks of bias, inconsistency, indirectness and impression.

Figure 1: Study Selection Process

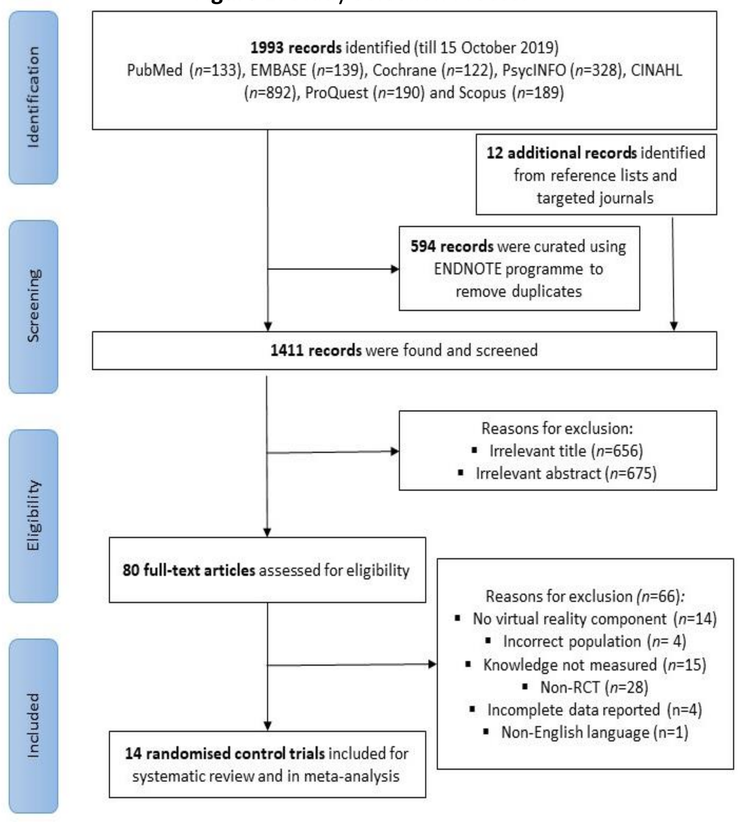

Figure 2: Forest plot of effect size in knowledge scores

Study name	Statistics for each study: Hedges's g	Z-Value	p-Value	Sample size: VR training	Control	Year	Country	Age
Bayramet al 2019	0.39	1.80	0.07	43	43	2019	Turkey	18.97
Bilen 2018	0.01	0.02	0.99	15	14	2018	USA	24.10
Chang et al 2019	0.22	0.88	0.38	32	32	2019	Taiwan	24.00
Cobbett et al 2016	-0.28	-1.03	0.30	27	28	2016	Canada	25.00
Farra et al 2013	0.72	2.44	0.01	22	25	2013	USA	46.50
Farra et al 2015	0.09	0.48	0.63	54	52	2015	USA	34.50
Gu et al 2017	0.85	2.17	0.03	13	14	2017	China	19.15
Haerling 2018	0.15	0.69	0.49	37	44	2018	USA	32.92
Ismailoglu et al 2018	0.04	0.18	0.86	33	32	2018	Turkey	20.47
Kim & Suh 2018	0.82	3.23	0.00	34	32	2018	Korea	22.70
LeFlore et al 2012	0.65	3.08	0.00	46	47	2012	USA	25.70
Loar et al 2007	-0.37	-1.24	0.21	24	21	2007	USA	25.70
Padilha et al 2019	1.11	3.40	0.00	21	21	2019	Portugal	19.90
Tan et al 2017	2.28	9.01	0.00	57	46	2017	Singapore	20.95
	0.47	2.66	0.01					

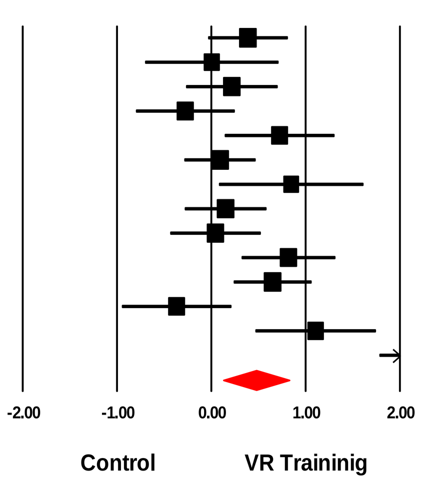

Table 1: Subgroup analyses of virtual reality training for knowledge scores

Design	Subgroups	No. of studies (ref)	Sample size (n)	Hedges' *g*	Overall effect	Subgroup difference
Population nature	Associate degree and postgraduate	3 (h, l,m)	168	0.28	Z = 0.73, *p* = 0.46	Q = 0.31, *p* = 0.58
	Undergraduate	11(a,b,c,d,e,f,g,i,j,k,n)	741	0.53	Z = 2.53, *p* = 0.01*	
Content	Non procedural	7 (b,c,d,h,k,l,m)	409	0.22	Z = 1.18, *p* = 0.24	Q = 2.22, *p* = 0.14
	Procedural	7 (a,e,f,g,i,j,n)	500	0.73	Z = 2.47, *p* = 0.01*	
Level of Immersion	Low to moderate	11 (a,d,e,g,h,i,j,k,l,m,n)	710	0.50	Z = 2.37, *p* = 0.02*	Q = 0.10, *p* = 0.75
	Moderate to high	3(k,l,g)	199	0.37	Z = 1.00, *p* = 0.32	
Provider	Self-guided	10(a,b,e,f,g,h,j,k,l,n)	683	0.56	Z = 2.48, *p* =0.01*	Q = 0.83, *p* = 0.36
	Facilitator-delivered	4(c,d,i,m)	226	0.25	Z = 0.94, *p* = 0.35	
Platform	Mobile application	3(a,c,j)	216	0.47	Z = 2.74, *p* = 0.01*	Q < 0.01, *p* = 0.98
	Computer software	11(b,d,e,f,g,h,i,k,l,m,n)	693	0.47	Z = 2.06, *p* = 0.04*	
Length of sessions	≤ 30 mins	6(a,e,f,g,h,n)	450	0.74	Z = 2.17, p = 0.03*	Q = 1.594, *p* = 0.45
	> 60 mins	6 (b,c,d,m,k,l)	328	0.23	Z = 1.02, *p* = 0.31	
	Unknown	2(i,j)	131	0.43	Z = 1.11, *p* = 0.27	
Number of sessions	Single	11(b,c,d,e,f,h,i,k,l,m,n)	730	0.42	Z = 1.89, *p* = 0.06	Q = 0.50, *p* = 0.48
	Multiple and user-determined	3(a,g,j)	179	0.61	Z = 3.93, *p* < 0.001***	

Hedges' g =Effect size; Q=Cochran's statistics; Z= z-statistic; *p<0.05; **p<0.01;

Reference: [a](Bayram et al., 2019); [b](Bilen, 2018); [c](Chang et al., 2019); [d](Cobett et al., 2016); [e](Farra et al., 2013); [f](Farra et al., 2015); [g](Gu et al., 2017); [h](Haerling, 2018); [i](Ismailoglu et al., 2018); [j](Kim et al., 2018); [k](LeFlore et al., 2012); [l](Loar, 2007); [m](Padilha et al., 2019); [n](Tan et al., 2017)

Discussion

This meta-analyses revealed statistically significant higher knowledge scores with a small-to-medium effect in the VR group as compared to the control group. This is consistent with previous reviews, and the learning mechanism can be explained by Kolb's experiential learning model.

Subgroup analysis identified that self-guided training of procedural content using low-to-moderate immersion among undergraduate nursing students appeared to be more effective in improving knowledge scores, likely due to the technology-literate millennial generation and self-motivated learning which improves encoding and retaining of information. An effective training regime consisted of short interval training (≤30mins each) for multiple or user-determined number of sessions, consistent with previous studies that reports initial attention gaining effect. Random-effects meta-regression did not identify any effect of the covariates.

The overall quality of evidence is very low due to lack of reporting concealment in selected trials, the subjective nature of knowledge as an outcome, for which participants could not be blinded. Lack of trial protocol registration, lack of ITT and missing data management also caused biased estimates of treatment effect.

This is the first systematic review that provided the most up-to-date evidence on this topic, conducted with robust search strategy (i.e. only RCTs included to ensure scientific credibility) and statistical analysis to account for small sample sizes and covariates on the effect size. Limitations of the review includes limiting to RCTs published in English language affecting generalisation of findings; small sample sizes which may induce small study effects; high heterogeneity; and need for cautious interpretation of findings given the very low quality of evidence.

This review also provides suggestions for design elements of future VR training programs. Future studies should examine the long-term impact and cost-effectiveness of VR training; as well as translation of knowledge gain to real-world clinical settings.

Conclusion

Nursing schools must ensure that students have sufficient knowledge to provide safe and competent care. VR training is an innovative and viable teaching strategy which delivers experiential learning and can be used to enhance learning outcomes. VR training significantly improved knowledge among nursing students, but the low quality of evidence limits confidence in implementation. Further research is required to evaluate the cost-effectiveness and long-term impact of VR training on the learning outcomes of nursing students.

References available at https://doi.org/10.1016/j.nedt.2020.104655

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