Research Square

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The Impact of the Fidelity of Simulation on Medical Undergraduate Education: A Meta-Analysis

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Abstract

Background: With the development of science and technology, simulation-based education has also developed rapidly. However, whether the fidelity level of simulators has a positive correlation with medical students' learning outcomes is controversial. This study aims to compare the theoretical knowledge, skill performance and confidence of undergraduate medical students through meta-analysis according to the fidelity level of the simulator.

Methods: Two researchers independently searched the PubMed database, the Cochrane Library, and the Embase database through October 20, 2020, to retrieve articles on the differences in effectiveness between high-fidelity simulators and low-fidelity simulators in undergraduate medical education. The Cochrane risk of bias tool was used to evaluate all included literature. Quantitative meta-analysis of the included literature was performed with Review Manager 5.3.

Results: Fifteen studies met the inclusion criteria, 11 of which were meta-analysed. Meta-analysis showed whether there were differences in students' theoretical knowledge [standardized mean difference -0.51; 95% *CI* -1.30□0.29□*P*=0.21], skill performance [standardized mean difference -0.26; 95% *CI* -0.87□0.35, *P* = 0.40], and confidence [standardized mean difference 2.53; 95% *CI* -1.05□6.10, *P* = 0.17]: there were no significant differences between high-fidelity simulators and low-fidelity simulators.

Conclusions: In medical undergraduate education, students who experience low-fidelity simulator training are not inferior to students who learn from high-fidelity simulators in their theoretical knowledge, skill performance, or confidence.

Background

Since its birth in the 1960s and with the rapid development of human model simulators, simulation-based teaching has been integrated into most clinical courses [1]. Moreover, many experiments have fully demonstrated the positive effects of simulation-based theoretical knowledge and clinical skills [2, 3]. Lack of clinical practice is a common problem in undergraduate medical education. Training and teaching based on simulation can provide medical students with practical application experience. Training and teaching based on simulation is an ideal teaching mode to provide medical students with theoretical knowledge and hands-on practice by constructing simulation environments instead of real scenes; this approach is considered to have great development potential.

With the development of modern technology and advances in synthetic materials technology, current simulators are able to provide a very realistic environment, reproducing realistic changes and providing feedback. High-fidelity simulation (HFS) can be used for training and to immerse users in complex and realistic scenarios by providing realistic feedback. However, some simulators with limited functions can only provide a specific simulation environment and cannot provide all realistic feedback; this is called low-fidelity simulation (LFS).

From personal experience, it seems that there is a positive correlation between the fidelity of the simulator and the learning performance of medical students, but several studies have found that LFS is no less effective at improving knowledge and skills than HFS [4]. Studies have found that compared with LFS, HFS can not only fail to better than LFS in improve students' abilities in terms of knowledge and skills but can also cause them to have blind confidence and seriously overestimate their abilities. This is an undesirable outcome because one of the most common cognitive biases that leads to clinical diagnosis errors is overconfidence [5]. Therefore, to explore the effect of simulator fidelity on undergraduate medical education, a meta-analysis based on existing studies is necessary.

The purpose of this meta analysis was to objectively evaluate the impact of using high-fidelity simulators or low-fidelity simulators on the theoretical knowledge, skill performance and confidence of undergraduate medical students.

Methods

Search strategy

Literature retrieval: Two researchers (Y.H. and X.C.) independently searched PubMed, the Cochrane Library, and Embase online and collected randomized controlled studies on HFS and LFS in medical undergraduate education; the date range was January 1, 1995, to October 20, 2020. The online search was supplemented by a manual search and follow-up search, and the authors were asked for the full text and original data. Search keywords: ("high patient simulators" or "high fidelity simulation") and ("low fidelity simulation" or "static" or "low patient simulators) and ("medical education" or "undergraduate education").

Data screening and extraction

Inclusion criteria: 1. Type of study: randomized controlled study; 2. Research objects: Students receiving undergraduate medical education; 3. Intervention measures: A high-fidelity simulator was used in the experimental group and a low-fidelity simulator was used in the control group. Specific information on the simulator was mentioned in the paper, and the sizes of the experimental group and control group were clear. 4. Outcome indicators: theoretical knowledge, skill performance and confidence.

Study selection: All possible eligible study titles were screened by two independent reviewers (Y.H. and X.C.), not excluding abstracts and full text. After filtering based on the titles of the articles, both reviewers reviewed the remaining papers and identified articles that met the inclusion criteria. Differences between the two reviewers were resolved by discussion or by arbitration by the third investigator. We define the fidelity of the simulator as the physical properties of the simulator. High-fidelity simulators are "those that provide physical examination, display vital signs, physiological responses, intervention (through a computer interface) and allow certain operations to be performed on them (endotracheal intubation, intravenous intubation, face mask, etc.)." Low-fidelity simulators, on the other hand, are "static models that are otherwise limited by these capabilities" [6]. Out of 4,568 potentially relevant articles, the selection based on titles and abstracts resulted in 270 relevant studies. After reviewing the papers, 36 studies were retained. The 36 full-text articles were systematically reviewed to confirm their eligibility (Fig. 1).

Grading the evidence

Data collection: two independent reviewers (Y.H. and X.C.) used spreadsheet data extraction to extract the results of the randomized controlled trials. The evidence was evaluated according to the Cochrane bias risk tool, and discussion or arbitration by a third researcher was used to settle differences in the evaluation. If the articles reported uncertain data or had missing data, the author was contacted to obtain the missing details so that enough original data could be obtained for the meta-analysis.

Endpoints

The main end point is to determine that low-fidelity simulators are not inferior to high-fidelity simulators in terms of the theoretical knowledge and skill performance of medical undergraduate students. The secondary endpoint is to determine whether there is a difference in the confidence of participants between those taught with low-fidelity simulators and those taught with high-fidelity simulators.

Statistical analyses

The data were analysed using a combination of quantitative and qualitative evidence. Results from tests that occurred at similar time points (such as at the end of a performance skills course) were reported using the standardized mean difference (SMD) to allow direct comparison [7]. We used random effects meta-analysis to quantify the results of more than one study. The SMD, 95% confidence interval and statistical heterogeneity were calculated by inputting the data into Review Manager 5.3 (Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark). We quantified the inconsistencies between studies, and for the analysis of three or more studies, using I^2 statistics, we determined the percentage of variability due to chance. $I^2 > 50\%$ indicates the existence of high inconsistency or heterogeneity, so a random effects model was chosen [7]. Funnel plot was used to observe publication bias.

Results

Using the above search strategy, we identified 4,568 potentially relevant studies. Fifteen of the studies met the criteria. The characteristics of the 15 studies included in this meta-analysis are listed in Table 1. Random assignment was used in all the studies. Thirteen studies compared high-fidelity simulators with low-fidelity simulators, and two studies compared high-fidelity simulators with static simulators. Figure 2 summarizes the risk of bias assessment. Eight studies did not describe the method of random allocation [8–15]. Only three studies detailed the generation of allocation. Four studies [5, 16, 17] used a blinded method, while one study [5, 16–18] clearly indicated that no blinding was used [19]. Six studies blinded the evaluators [5, 8–10, 17, 18]; participants in one study were randomly assigned, but the researchers who assessed their scores were not [20]. One study had risk of bias due to missing results [13]. There was a low risk of publication bias in all the studies.

Table 1
Characteristics of the studies included in the analysis

Author (Year)	Country	Random assignment	Expertise level of students	Method		Sample size experimental/control	Outcomes	
				Experimental group	Control group		Knowledge	Skill Performance
Adams et al. (2015) [8]	USA	Y	1st-2nd year medical students AND 1st-year physician assistant students	high-fidelity simulation activities	a DARTsim electrocardiogram (ECG) soft- ware simulator	9/10	No significant difference	Negative outcome
Ahad et al. (2013) [9]	USA	Y	3rd-4th year medical students	High-Fidelity Model	Low-Fidelity Model	16/16	Not evaluated	No significant difference
Banaszek et al. (2017) [16]	Canada	Y	pre-clerkship level medical students	a high-fidelity virtual reality arthroscopic simulation	a bench-top arthroscopic setup	16/16	Not evaluated	Positive outcome
Chen et al. (2015) [10]	Canada	Y	senior undergraduate nursing students	human patient simulator	digital sounds on a computer	21/21	Not evaluated	Low-fidelity simulation performs as well or better than high-fidelity simulation
Curran et al. (2014) [11]	Canada	Y	3rd-year medical students	high-fidelity manikin simulator	low-fidelity manikin simulator	31/35	Not evaluated	No significant difference
Denadai et al. (2014) [18]	Brazil	Y	1st-2nd year medical students	high-fidelity chicken leg skin	low-fidelity rubberized line	12/12	Not evaluated	No significant difference
King and Reising (2011) [12]	USA	Y	senior nursing students	a high-fidelity simulation	a static simulation	24/25	No significant difference	Positive outcome
DeStephano et al. (2015) [17]	USA	Y	2nd-4th year medical students	a high-fidelity, computer-controlled mannequin	an obstetrical abdominal-pelvic model	47/46	Not evaluated	No significant difference
Massoth et al. (2019) [5]	Germany	Y	4th-year medical students	a high-fidelity simulated Advanced Life Support training session	a low-fidelity simulated Advanced Life Support training session	67/68	No significant difference	Low-fidelity simulation performs as well or better than high-fidelity simulation
McCoy et al. (2018) [19]	USA	Y	4th-year medical students	a high-fidelity simulator	a low-fidelity Resusci Anne CPR manikin	35/35	Not evaluated	Positive outcome
Mills et al. (2016) [13]	Australia	Y	1st-year paramedicine students	high environmental fidelity simulations (LFenS)	low environmental fidelity simulations (LFenS)	19/20	Not evaluated	Positive outcome
Mutlu et al. (2019) [14]	Turkey	Y	3rd-4th year nursing students	high-fidelity simulators (interactive patient simulators)	low-fidelity simulators (computer and video)	36/35	Positive outcome	Not evaluated
Nimbalkar et al. (2015) [20]	Gujarat	Y	3rd-year medical students	SimNewB (an inter- active high fidelity simulator)	low fidelity Resusci® Baby Basic	50/51	No significant difference	No significant difference

Visual inspection of the funnel plots indicated asymmetry. The asymmetry of the funnel plots may be due to an insufficient number of trials (leading to a sma effect) and significant statistical heterogeneity.

Author (Year)	Country	Random assignment	Expertise level of students	Method		Sample size experimental/control	Outcomes	
				Experimental group	Control group		Knowledge	Skill Performance
Tosterud et al. (2013) [15]	Norway	Y	1st-3rd year nursing students	High-fidelity patient simulator	Static mannequin	29/28	No significant difference	Not evaluated
Urdiales et al. (2020) [21]	Brazil	Y	1st-2nd year medical students	a high-fidelity Megacode Kelly Laerdal® mannequin	a low-fidelity model developed by the researcher	30/30	No significant difference	Not evaluated

Visual inspection of the funnel plots indicated asymmetry. The asymmetry of the funnel plots may be due to an insufficient number of trials (leading to a sma effect) and significant statistical heterogeneity.

Outcomes

Six studies [5, 8, 10, 14, 20, 21] quantitatively compared the mastery of theoretical knowledge of undergraduate medical students exposed to HFS and LFS. There was high heterogeneity among the studies (I^2 = 93%, P < 0.00001), and a random effects model was used. The results showed that there was no significant relation between the fidelity of the simulator and the mastery of theoretical knowledge of medical undergraduates [WMD and its 95% CI were − 0.51 (-1.30 ~ 0.29), P = 0.21] (Fig. 3). King and Reising [12] compared the effectiveness of static simulation and HFS in the teaching of advanced heart life support guidelines. The results showed that there was no significant difference in theoretical knowledge between the static simulation group and the HFS group (P = 0.1455, a = 0.05). It seems that the funnel plot is asymmetrical (Fig. 4).

Four studies [8, 10, 18, 20] quantitatively compared the professional skill performance of undergraduate medical students taught via HFS and LFS. There was high heterogeneity among the studies (I^2 = 71%, P = 0.02), and a random effects model was used. The results showed that there was no significant relation between the fidelity degree of the simulator and the degree of professional skills mastery of the medical undergraduates [WMD and its 95% CI were − 0.26 (-0.87 ~ 0.35), P = 0.40] (Fig. 5). Four studies obtained positive results: Banaszek et al. [16], King et al. [12], Mills et al. [13], and Moccy et al. [19] The results showed that the clinical skills performance of students in the HFS group after receiving HFS teaching was significantly different from that of students in the LFS group (P < 0.05). The funnel plot is symmetric (Fig. 6).

Three studies [11, 15, 18] quantitatively compared participants' confidence after receiving HFS and LFS teaching and training. There was high heterogeneity among the studies (I^2 = 98%, P < 0.00001), and a random effects model was used. The results showed that there was no statistically significant effect of simulator fidelity on the confidence of medical undergraduates [WMD and its 95% CI were 2.53 (-1.05 ~ 6.10), P = 0.17] (Fig. 7). The funnel plot is asymmetrical (Fig. 8).

Discussion

This meta-analysis provides data for evidence-based education by comprehensively analysing undergraduate medical education under different backgrounds and types of simulation. In this study, it was found that there was no significant difference between HFS and LFS in terms of students' theoretical knowledge, clinical skills or improved confidence.

Both high-fidelity and low-fidelity simulators can improve students' theoretical knowledge and clinical skills [20]. There is no difference in theoretical knowledge and clinical skills, and similar results have been reported in many studies [8, 20, 21]. These results may suggest that the teaching effect of LFS can be equivalent to that of HFS in medical undergraduate education. However, some studies have found that high-fidelity simulators are superior to low-fidelity simulators in improving students' clinical skills [12, 14].

In terms of economy, the cost and price of high-fidelity simulators are much higher than those of low-fidelity simulators [22]. This leads to the low cost performance of high-fidelity simulators in medical undergraduate education. Second, the majority of students from both groups had strong positive expectations of the value of HFS. Before the course, only the majority of the HFS group adhered to this belief, while many participants in the LFS group changed their views and did not consider LFS training to be inferior [19]. This suggested that LFS training did not discourage participants but rather made them more confident.

As the simulation level increases, the cognitive burden of inexperienced students also increases, and the complexity of the working environment will distract students' attention, leading to low learning efficiency and even lack of knowledge [23]. Some literature also suggests that students will feel pressured by high-fidelity simulators because of the highly simulated environment they create. However, students who have basic knowledge of clinical skills can refine their performance by entering the "deep" simulated environment of high-fidelity simulators [13]. It is completely feasible to conduct low-fiedlity simulations for students with little experience [21]. This has great educational value.

The limitations of this paper are as follows. First, the participants in our included studies were undergraduate medical students whose specific training and education levels may have influenced the outcomes in a way that is different from the way medical professionals are assessed. Second, the high heterogeneity of this study may be due to the heterogeneity of the intervention measures and measurement schemes across the included studies. This article includes only research published in English. There are too few studies based on quantitative analysis, and the funnel plots seem asymmetric. Therefore, more clinical studies are needed to determine the relation between the fidelity of the simulator and medical undergraduate learning outcomes.

Conclusions

According to the results of this study, there is no positive relation between education outcomes and the fidelity of the simulator. This finding may be associated with the education level of our sample, and whether it is replicable in professional medical personnel needs further research. In terms of undergraduate medical education, HFS does not have high investment returns, and the reasonableness of its use in medical undergraduate education is questionable. More clinical trials are needed to provide evidence.

Abbreviations

HFS
High-fidelity simulation
LFS
Low-fidelity simulation
SMD
standardized mean differenc

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

Not applicable

Competing interests

The authors declare that they have no competing interests..

Funding

Not applicable

Authors' contributions

All authors contributed to the design of this study. Y.H. and T.Y. proposed the concept and design of this research. Y.H. and X.C. conducted literature search and data extraction. Statistical analysis was performed on Y.H. and X.C.. S.N. drafted the manuscript. T.Y. participated in the coordination and assisted in drafting the manuscript. All authors approved the final version of this article.

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Figures

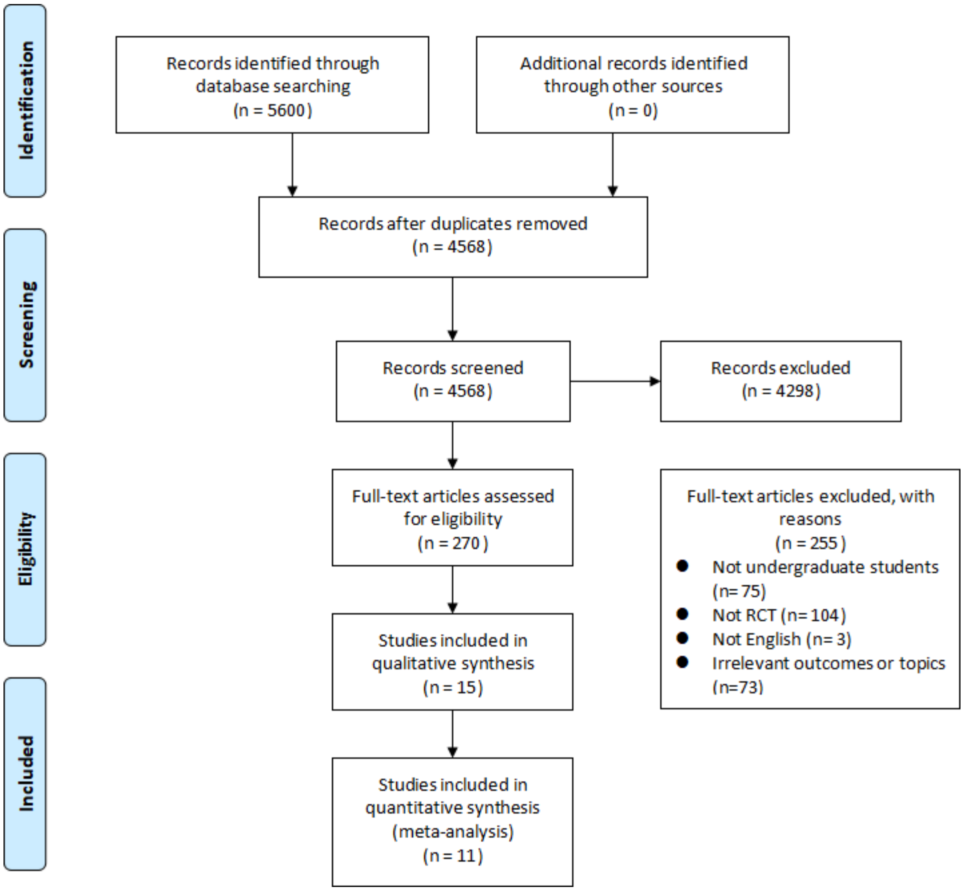

Figure 1

Flow chart of study screening.

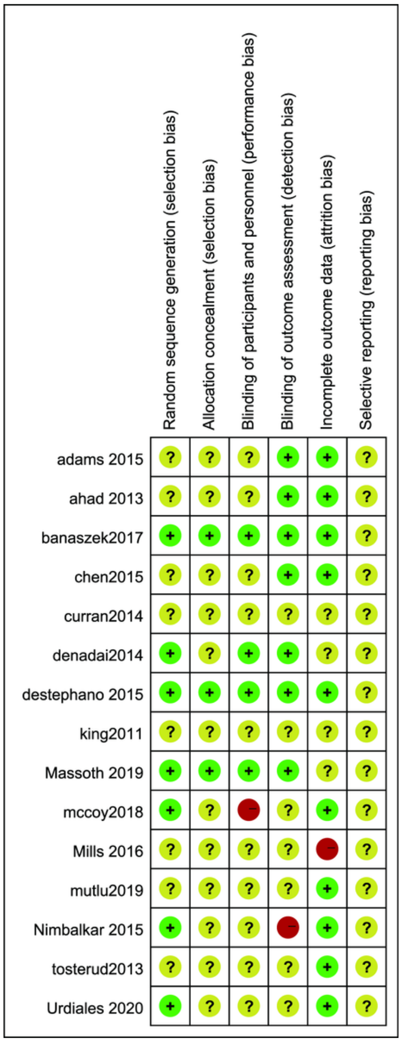

Figure 2

Risk assessment diagram of studies included in the meta-analysis.

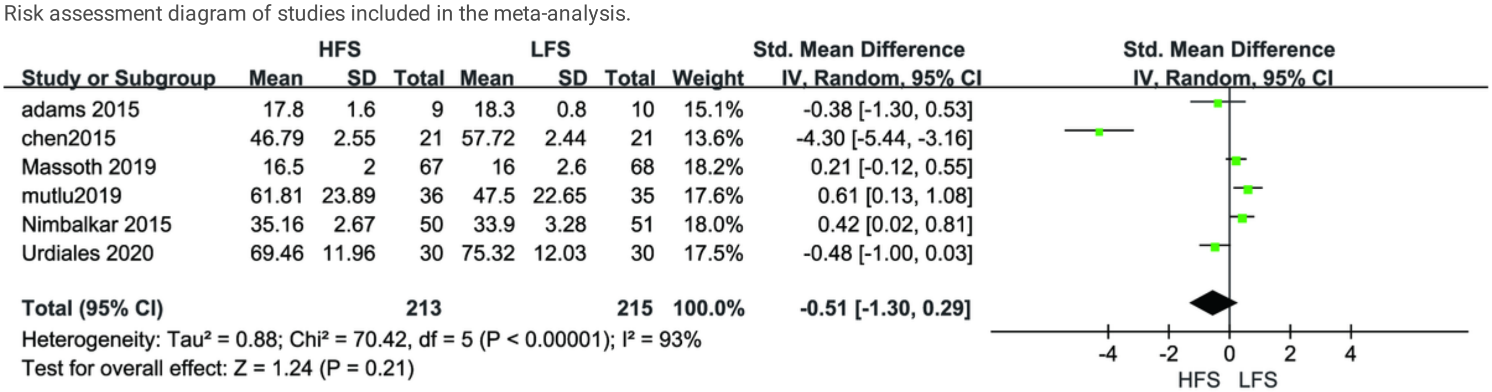

Figure 3

Forest plot of the influence of HFS and LFS on the theoretical knowledge.

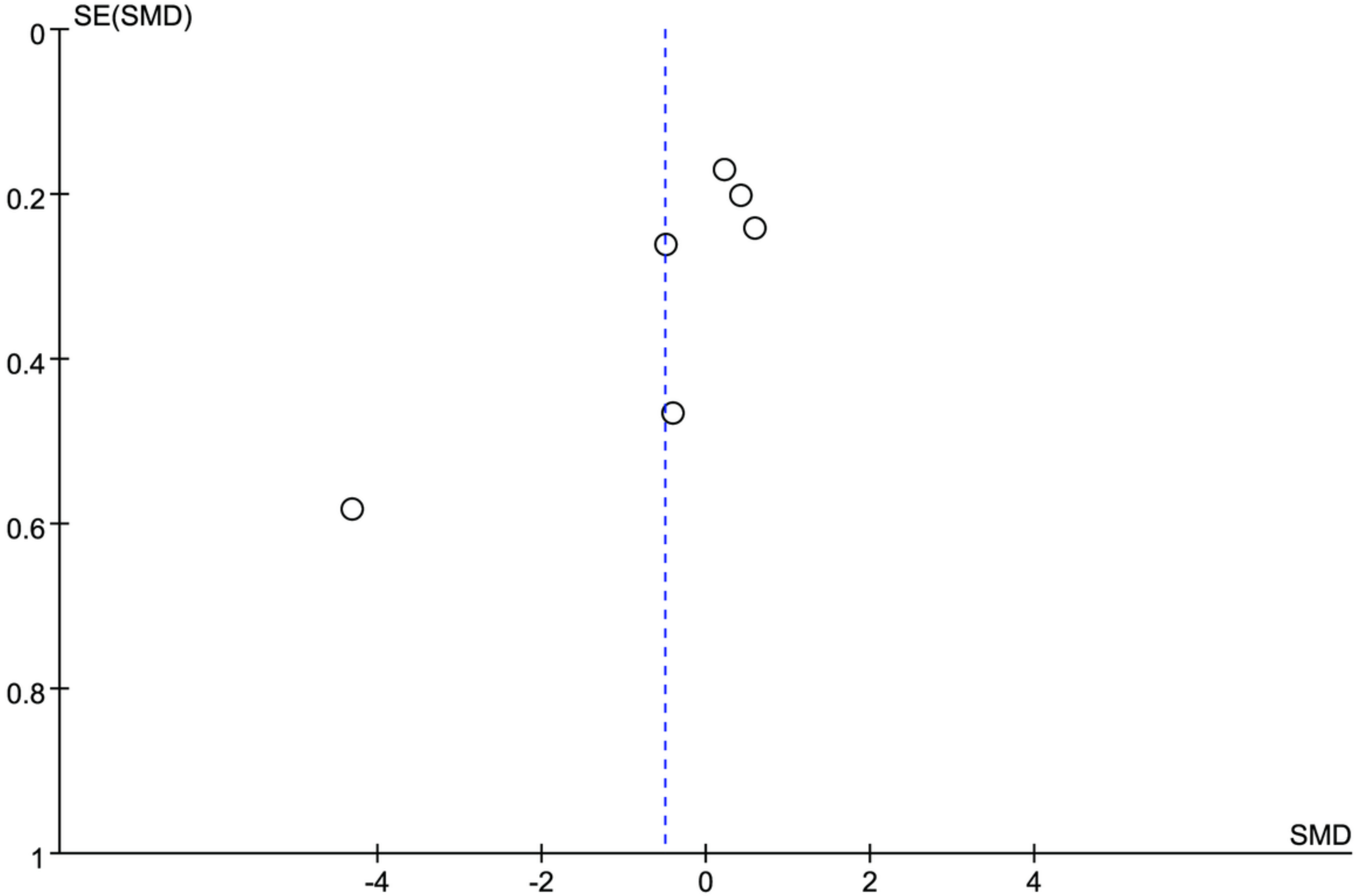

Figure 4

Funnel plot of the effect of fidelity on the theoretical knowledge of medical undergraduates.

	HFS			LFS				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
adams 2015	16.4	4.7	9	21.3	5.8	10	19.3%	-0.88 [-1.84, 0.07]
denadai2014	24.42	1.5	12	24.42	1.24	12	22.5%	0.00 [-0.80, 0.80]
chen2015	3.4	0.29	21	3.6	0.26	21	26.4%	-0.71 [-1.34, -0.09]
Nimbalkar 2015	31.46	6.14	50	29.67	5.57	51	31.8%	0.30 [-0.09, 0.70]
Total (95% CI)			**92**			**94**	**100.0%**	**-0.26 [-0.87, 0.35]**

Heterogeneity: Tau² = 0.26; Chi² = 10.33, df = 3 (P = 0.02); I² = 71%
Test for overall effect: Z = 0.84 (P = 0.40)

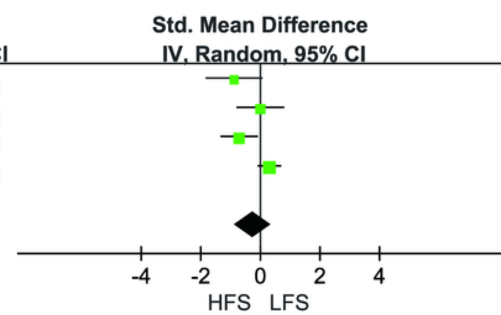

Figure 5

Forest plot of the influence of HFS and LFS on the skill performance.

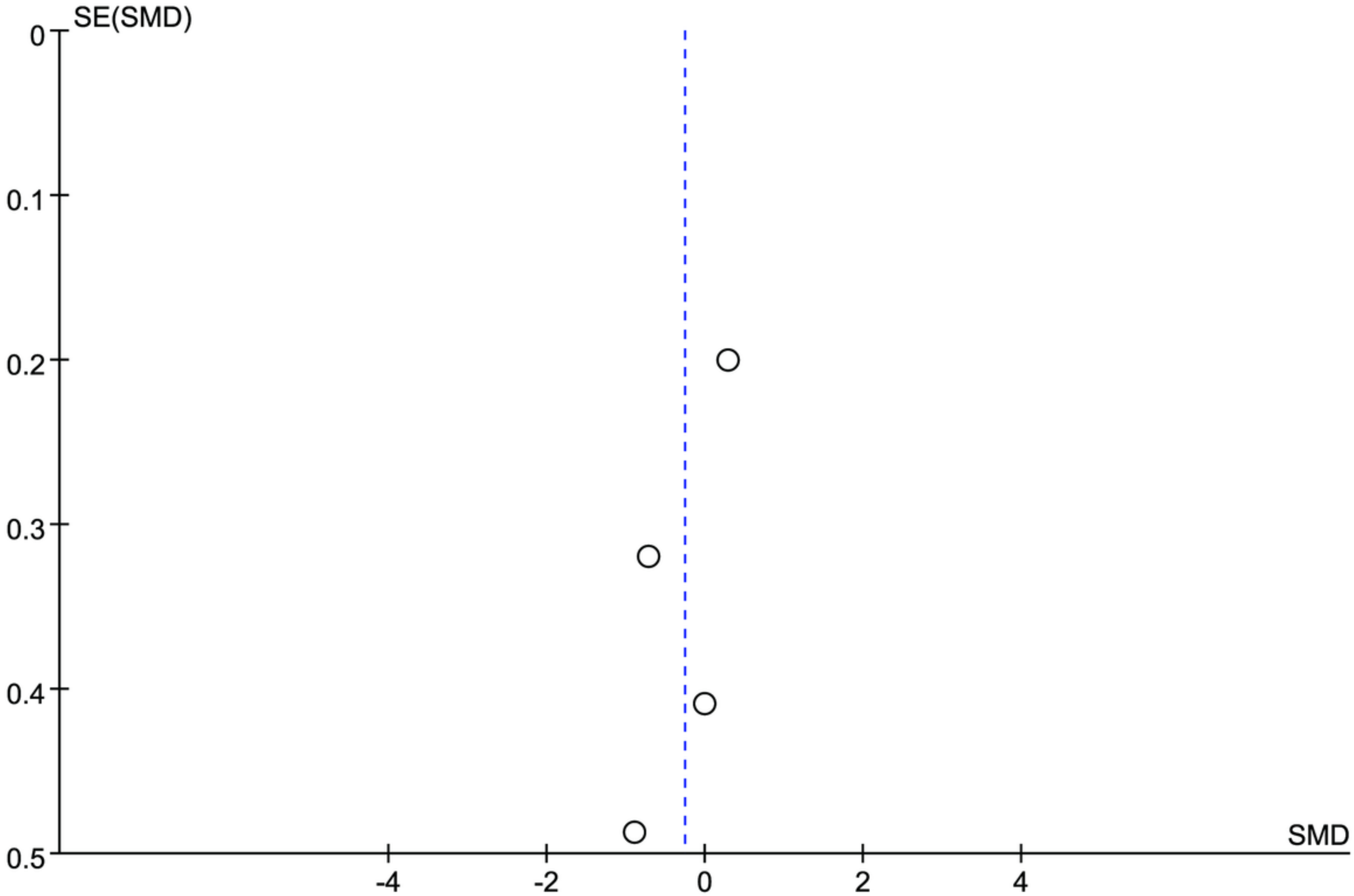

Figure 6

Funnel plot of the effect of fidelity on the skill performance of medical undergraduates.

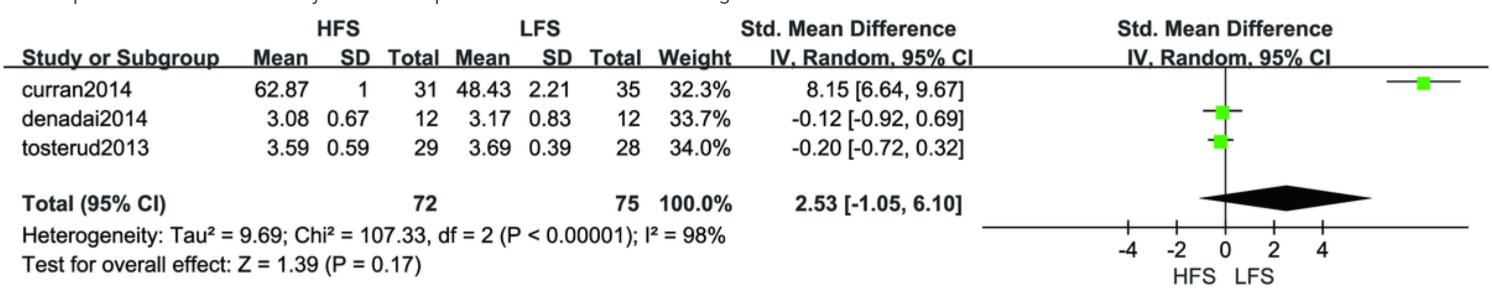

Figure 7

Forest plot of the influence of HFS and LFS on the confidence.

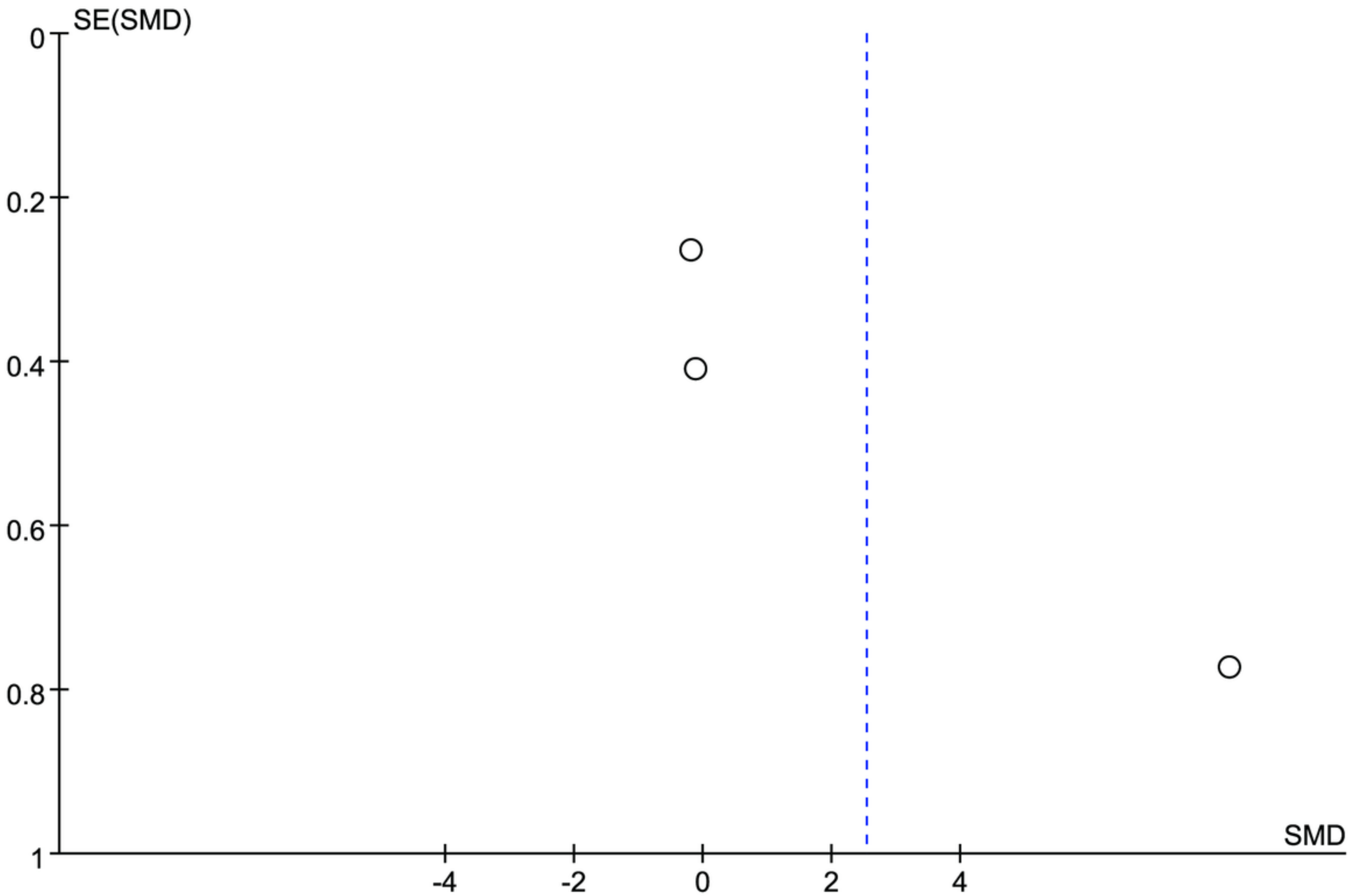

Figure 8

Funnel plot of the effect of fidelity on the confidence of medical undergraduates.

Supplementary Files

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