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Research article

Spatial abilities training in the field of technical skills in health care: A systematic review

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ABSTRACT

Objective: To conduct a systematic review of the effect of interventions on spatial abilities in the field of technical skills in health care.
Methods: A literature search was conducted up to November 14, 2017 in Scopus and in several databases on EBSCOhost platform. Citations were obtained, articles related to retained citations were reviewed and a final list of included studies was identified. Methods in the field of technical skills relating an intervention to spatial abilities test scores between intervention groups or obtained before and after the intervention were identified as eligible. The quality of included studies was assessed and data were extracted in a systematic way.
Results: A series of 5513 citations was obtained. Ninety-nine articles were retained and fully reviewed, yielding four included studies. No difference in the Hidden Figure Test score after one year was observed after residency training in General Surgery of at least nine months. A first-year dental curriculum was not found to elevate the Novel Object Cross-Sections Test score ($P = 0.07$). A two-semester learning period of abdominal sonography was found to increase the Revised Minnesota Paper Form Board Test score ($P < 0.05$). A hands-on radiology course using interactive three-dimensional image post-processing software consisting of seven two-hour long seminars on a weekly basis was found to amplify the Cube Perspective Test score ($P < 0.001$).
Conclusion: Spatial abilities tests scores were enhanced by courses in abdominal sonography and hands-on radiology, but were not improved by residency training in General Surgery and first-year dental curriculum.

1. Introduction

In a systematic review, visual-spatial perception has been correlated with operative abilities in the field of surgery at the end of a training programme, but not found in experts [1]. Also, visual spatial tests have been correlated with technical performance in surgical trainees in a systematic review [2]. Another systematic review in the health area has found spatial abilities test score to be positively correlated to the quality of technical skills performance in novices and intermediates but negatively correlated to the duration of technical skills performance in novices and intermediates [3]. This systematic review has not identified any correlation in competent individuals or experts [3]. These findings imply that spatial abilities have been important in the learning process of technical skills in surgery [1,2] and more broadly in health care [3].

Three phases have been identified in the Fitts and Posner's theory of motor skill acquisition: cognitive, associative and autonomous [4]. The cognitive phase involved in learning novel first time experienced non-repetitive tasks have been related to spatial abilities by Ackerman's theory of ability determinants [5,6]. Spatial abilities have been found important in the cognitive phase of learning a novel technical skill in health care [3]. Spatial abilities have not been correlated to technical skills performance in surgery [1] and health care [3] in individuals in the autonomous phase.

Basic factors involved in individual differences in spatial abilities have been identified: environmental, genetic, hormonal, and neurological [7]. In the field of cognitive psychology [8,9,10] and anatomy education [11,12,13,14,15], males have been found to have better spatial abilities. Further, a negative correlation of the aging process and spatial

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abilities has been identified in a systematic review [16]. A peak in the twenties and a decay afterward have been observed for spatial abilities [17,18].

It has been written that 'combining knowledge of the influences of both instructional design and learners' individual differences may yield the best predictors of success in training programmes'. [19]. This knowledge should be based on scientific evidence. Genetic, hormonal, neurological, environmental [7], sex [8,9,10,11,12,13,14,15], and age [16,17,18] factors have been found to impact on spatial abilities. Theoretically, improving spatial abilities by acting on these factors would improve quality and duration of the technical skills performance in health care.

Among these factors, environmental have been related to practice involving spatial abilities such as previous testing in spatial abilities [20], academic programme [21] and vocational activities [7]. Spatial abilities have been correlated to learning in science, technology, engineering, and mathematics (STEM) [22,23,24]. The malleability of spatial skills in the STEM domain have been studied in a systematic review [25]. Video games, a semester-long spatially relevant course and spatial task training have been identified to improve spatial abilities [25].

Technical skills in health care are a subset of technology within the STEM domain. A systematic review of the education and psychology literature up to 2009 by Uttal and colleagues [25] never targeted specific research in the health care field. There is a need to choose platforms that will likely cover all articles related to the specific field of technical skills in health care, the results of this study could identify strategies improving spatial abilities that could potentially improve technical skills performance in learners. The objective of this systematic review was to evaluate the effect of interventions on spatial abilities in the field of technical skills in health care.

2. Methods

The reporting of the systematic review followed the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) [26] and a research protocol was developed prior to the study. Two reviewers (C.B. and J.L.) independently conducted the following steps in the systematic review: screened the citations, full text articles and reference lists of included studies; assessed the quality of the included studies; extracted data from included studies and conducted qualitative synthesis and choice of studies for the meta-analysis. Any conflicts were discussed and consensus was reached.

2.1. Search strategy

The search strategies were developed by one information scientist (J. T.) and validated by another. No language restrictions were used when executing the search. The search was developed around concepts including 'interventions', 'technical skills' and 'spatial abilities' and related keywords.

The literature search was done up to November 14, 2017 in Scopus and in several databases on EBSCOhost platform (Medline with Full Text, Cinahl Plus with Full Text, ERIC, Education Source and PsycInfo). Search strategies are provided in Appendix 1.

2.2. Screening of citations and full-text articles

Title and abstracts from the literature search (records) were reviewed and those involving the field of technical skills in health care, an intervention, and a spatial abilities test were retained and the corresponding full-text articles were fully reviewed for inclusion. Citations related to proceedings, literature reviews, books, book sections, and theses were excluded. Methods in the field of technical skills in health care relating an intervention to spatial abilities test scores between intervention groups or obtained before and after the intervention were identified as eligible. References lists of included studies were screened for additional citations.

2.3. Quality and characteristics of eligible articles

The studies were assessed for quality and rated as low (-), intermediate (+), or high (++) using the Scottish Intercollegiate Guidelines Network-50 (SIGN-50) [27] selected based on a review of quality assessment tools [28].

Study type, sample size, information related to population (type of participants, country, gender and age), intervention, comparator, and outcomes were extracted from the included articles. Outcome of interest were spatial abilities test scores, compared between groups or compared between pre- and post-test assessment. Results for relationships between intervention in the field of technical skills in health care and spatial abilities test were extracted and described.

2.4. Statistical analysis

For the discrete variables, descriptive statistics included frequency and percent. For the continuous variables, median or mean and standard deviation (SD) or standard error of the mean (SEM) or range were considered. The level of statistical significance was established at < 0.05.

3. Results

Screening of citations, full-text articles and references of included studies; quality assessment and data extraction from included studies; qualitative synthesis and choice of potential studies for the meta-analysis were done by two independent reviewers (C.B. and J.L.), and conflicts between reviewers were discussed, a consensus was reached without the need of a third reviewer.

A summary of the selection of articles is shown in the PRISMA flow diagram of Figure 1. The literature search yielded 8815 citations plus three additional citation from references lists of studies identified for inclusion. After the duplicates were removed, 5513 citations were identified of which 5414 citations were ineligible and 99 were considered for full-text review. Of the 99 articles that were retained and had full-text review, 95 were excluded for the following main reasons (Appendix 2): not in the field of technical skill ($n = 7$), absence of spatial abilities test scores before and after an intervention ($n = 66$), absence of spatial abilities test score ($n = 18$), lack of information for data extraction ($n = 1$), literature review ($n = 3$). Additional reasons for exclusion for a given article are also shown in Appendix 2. In summary, four eligible articles corresponded to four eligible studies of which none were available for a meta-analysis.

3.1. Characteristics of the included studies

The characteristics of the four studies that met our including criteria are described in Appendix 3. All studies had a before and after design relating spatial abilities to technical skills in health care. In the four studies (Appendix 3) retained for the systematic review, three were prospective cohort studies [29,31,32] and one was prospective/retrospective study [30]. One of the studies [32] was assessed as low quality and the other three [29,31,32] as intermediate.

Several types of study participants were considered among the four studies: General Surgery resident [29] ($n = 1$), dentistry student [30] ($n = 1$), undergraduate psychology student [30] ($n = 1$), sonography student [31] ($n = 1$), medical student [32] ($n = 1$). Two of the studies were conducted in the United States of America [30,31], one in Germany [32],

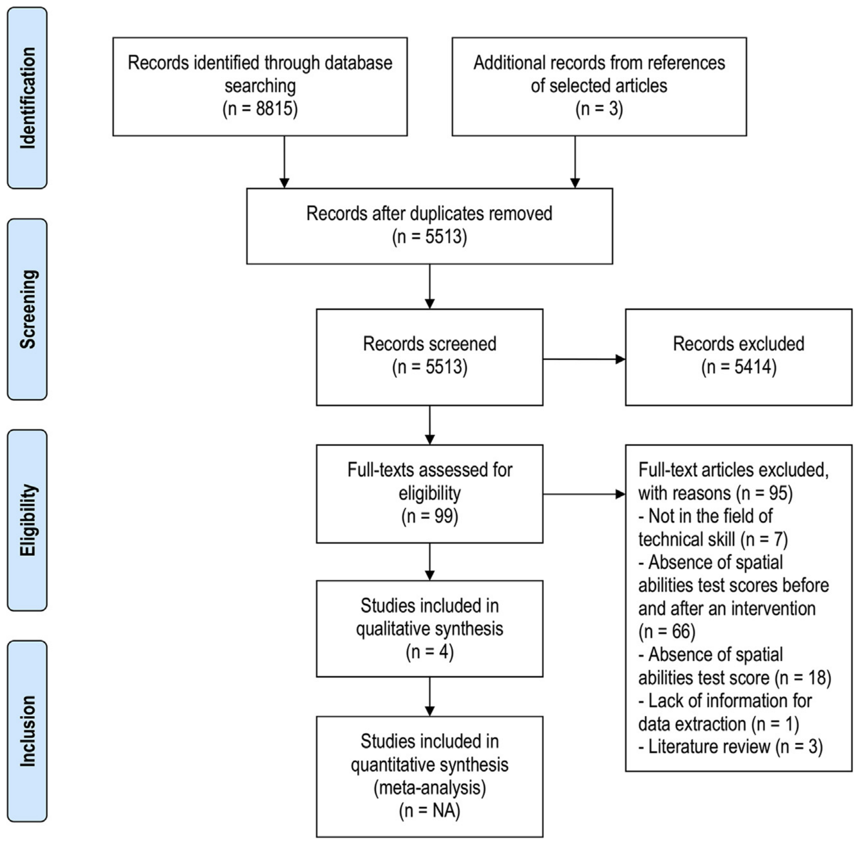

Figure 1. PRISMA flow diagram.

and one in an unspecified country [29]. The four studies included 370 participants of which 80 (21.6%) were females, 126 (34.1%) were males, and 164 (44.3%) were of unspecified sex. Age of participants was not specified.

The following spatial abilities test were used: Hidden Figure Test (n = 1) [29], Novel Object Cross-Section Test (n = 1) [30], Tooth Cross-Sections Test (n = 1) [31], Revised Minnesota Paper Form Board Test (n = 1) [31], and Cube Perspective Test (n = 1) [30]. The time interval for retesting of spatial abilities varied from two-semester [31] to one year [29,30].

Interventions were heterogeneous: residency training in General Surgery [29], first-year dental curriculum [30], learning of abdominal sonography [31], and hands-on radiology course using interactive three-dimensional image post-processing software [32]. The time for interventions varied from seven weeks [32] to one year [30].

Spatial abilities test scores before and after an intervention were provided but not spatial abilities score between intervention group.

3.2. Narrative synthesis

The Hidden Figure Test score after one year was not changed by a residency training in General Surgery of at least nine month with a test-retest reliability correlation r of 0.87 [29]. A first-year dental curriculum was not found to elevate the Tooth Cross-Sections Test score ($P = 0.07$) [30]. A two-semester learning period of abdominal sonography was found to increase the Revised Minnesota Paper Form Board Test score with an effect size of 0.32 ($P < 0.05$) [31]. A hand-on radiology course using interactive three-dimensional image post-processing software consisting of seven two-hour long seminars on a weekly basis was found to amplify the Cube Perspective Test score of 11.8% ($P < 0.001$) [32]. A meta-analysis was not possible because of inconsistent reporting of the statistical results for spatial abilities test score.

4. Discussion

The objective of this study was to evaluate the interventions on spatial abilities in the field of technical skills in health care. Training in abdominal sonography [31] and hands-on radiology [32] were identified to enhance spatial abilities. Similar findings have been found in anatomy education with courses of anatomy [13,14,33]. The positive findings in this study were also similar to those of a large systematic review [25] where courses with spatial abilities content have been found to improve spatial abilities in the STEM domain. The use of video games and specific spatial task training that has been found to be factors to improve spatial abilities in this large systematic review [25] were not found in the current study. Spatial task training has been found to improve spatial abilities in a systematic review of spatial abilities training in anatomy education [33].

Residency training in General Surgery [29] and first-year dental curriculum [30] were not found to improve spatial abilities even if spatial abilites test score were related to operative procedures performance [29] and restorative dentistry practical laboratory classes [30]. The residency training in General Surgery [29] and first-year dental curriculum [30] were less specific compared to courses in abdominal sonography [31] and hands-on radiology [32]. Uttal and colleagues [25] have related improvement in spatial abilites with a semester-long spatially relevant course, but this might not apply to a residency training in General Surgery and first-year dentistry curriculum. A residency training program and a curriculum compared to more specific courses might introduce uncontrolled variables that could interfer with spatial abilities test score.

It was interesting to note in the study of Hegarty and collegues that the Tooth-Cross Sections Test was improved after a second testing in the control group consisting of undergraduate psychology students not being submitted to the first-year dental curriculum [30]. This was not found in the experimental group with the Novel Object Cross-Sections Test [30]. This could be explained by the practice effect and the different nature of the Tooth Cross-Sections Test compared to the Novel Object Cross-Sections Test.

Comparison between groups considered in the study of Hegarty and colleagues [30] were not included in this systematic review for several reasons. The intervention between second and fourth year and first and fourth year dental curriculum was not direct and specific to spatial skills training. Also, there were may be many differences between the groups with possible residual confounders. Furthermore, no difference were found with valid and reliable tests of spatial abilities while difference was found with the less valid Tooth-Cross Sections Test. Finally, the content on the specific skills to be learned in third and fourth year was not clear. It is known that spatial abilities are important in the first two years of dentistry and less so in the last two years [34,35,36].

The search of Uttal and colleagues done up to 2009 used Proquest related to thesis, ERIC and PsyInfo covering mostly the field of education and psychology [25]. It is interesting to note that a study published in 1986 by Gibbons and colleagues [29] has not been picked up by the study of Uttal and colleagues [25] nor one study published in 2009 by Hegarty and colleagues [30]. This validates the choice of databases in the actual study that was more likely to cover all articles related to the specific field of technical skills in health care. The need to perform a new search was also validated by the findings in this study of two new studies since 2009 [31,32].

The time of training in studies with positive findings in this review were seven weeks [32] and two-semester [31]. Is is unknown if a shorter distribution would achieve the same effect as related to technical skills performance. Shorter distribution such as 20 min [37], 10 days on a given month [38], 160 h over 25 days [14], 60 h over at least four weeks [39] have been identified in the training of spatial abilities in the field of anatomy education [33]. Also, it is unknown if students have reached their maximum peak of spatial abilities after these courses. A positive dose-dependent effect of computer-assisted learning of anatomy on spatial abilities has been demonstrated in a recent study [40].

Considering the large amount of literature correlating spatial abilities to the technical skills performance in surgery [1,2] and in health care [3], it was interesting to note that very few research have tried to mesure the impact of practicing a technical skill in health care on spatial abilities.

Sex [8,9,10,11,12,13,14,15] and age [16,17,18] have been found to be important factors of individual differences in spatial abilities. Age was not considered in the four included studies. Also, the improvement in spatial abilities was not correlated with sex in the two studies with positive findings [31,32].

The improvement of spatial abilities test score has not been found to be transferred to technical skills performance in the two articles with positive studies [31,32]. This transfer has not been found either in the systematic review of Uttal and colleagues [25]. Mental rotation training has been found to improve anatomy knowledge score in a single study [39].

Future studies will need to assess the use of video games and specific spatial abilities training as factors to improve spatial abilities in the field of technical skills performance in health care. Also, assuming individual differences in the peak amplitude for spatial abilities, the effect of timing and amount of intervention will need to be evaluated to reach a specified plateau in a given learner. Furthermore, specific course will need to be compared to general curriculum for the malleability of spatial abilities. Finally, studies will need to investigate the impact of increased spatial abilites test score on technical skills performance.

4.1. Limitations

The specific spatial abilities test were different in the four included studies. No study used the valid and reliable Mental Rotations Test [20,41] which is more often considered in studies relating spatial abilities to technical skills performance in health care [3]. Also, the evaluation of the practice effect of a given spatial abilities test in a control group compared to the experimental group was not provided in any of the included studies.

There was heterogeneity in the intervention studied. Interventions were applied in a wide range of health care fields: General Surgery [29], dental curriculum [30], sonography [31], and radiology [32]. Also, the time for interventions varied from seven weeks [32] to one year [30].

None of the included articles was rated as ‘high’ quality; one [32] was rated as ‘low’ and three [29,30,31] as ‘intermediate’. A meta-analysis was not possible in this systematic review because of the inconsistency in reporting statistical results of the spatial abilities test scores.

5. Conclusion

Spatial abilities test scores were enhanced by courses in abdominal sonography and hands-on radiology, but were not improved by residency training in General Surgery and first-year dental curriculum. In the future, specific courses will need to be compared to general curriculum for the malleability of spatial abilities.

Declarations

Author contribution statement

J. Langlois: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

C. Bellemare, J. Toulouse: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data.

G. A. Wells: Conceived and designed the experiments; Analyzed and interpreted the data.

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Competing interest statement

The authors declare no conflict of interest.

Additional Information

No additional information is available for this paper.

Appendix 1. Search strategies for concept of interventions, technical skills and spatial abilities

Scopus

TITLE-ABS-KEY ("technical skill*" OR "surgical skill*" OR "procedural skill*" OR simulat* OR "surgical abilit*" OR "surgical train*" OR "virtual realit*" OR "practical laborator*" OR neuroimag* OR radiolog* OR "medical imag*") AND TITLE-ABS-KEY (intervention* OR instruct* OR format* OR train* OR educat* OR teach* OR learn*) AND TITLE-ABS-KEY ("spatial abilit*" OR "spatial aptitude*" OR "spatial skill*" OR "visual spatial abilit*" OR "visual spatial aptitude*" OR "visual spatial skill*" OR "visuospatial abilit*" OR "visuospatial aptitude*" OR "visuospatial skill*" OR "visuo-spatial abilit*" OR "visuo-spatial aptitude*" OR "visuo-spatial skill*" OR "spatial visuali?ation abilit*" OR "spatial visuali?ation aptitude*" OR "spatial visuali?ation skill*" OR "visual perception*" OR "space perception*" OR "spatial perception*" OR "psychomotor test*" OR "psychomotor abilit*" OR "psychomotor aptitude*" OR "psychomotor skill*" OR "perceptual abilit*" OR "perceptual aptitude*" OR "perceptual skill*")

EBSCOhost

Databases: Medline with Full Text, Cinahl Plus with Full Text, ERIC, Education Source and PsycInfo

S4	S1 AND S2 AND S3
S3	"technical skill*" OR "surgical skill*" OR "procedural skill*" OR simulat* OR "surgical abilit*" OR "surgical train*" OR "virtual realit*" OR "practical laborator*" OR neuroimag* OR radiolog* OR "medical imag*"
S2	Intervention* OR instruct* OR format* OR train* OR educat* OR teach* OR learn*
S1	"spatial abilit*" OR "spatial aptitude*" OR "spatial skill*" OR "visual spatial abilit*" OR "visual spatial aptitude*" OR "visual spatial skill*" OR "visuospatial abilit*" OR "visuospatial aptitude*" OR "visuospatial skill*" OR "visuo-spatial abilit*" OR "visuo-spatial aptitude*" OR "visuo-spatial skill*" OR "spatial visuali?ation abilit*" OR "spatial visuali?ation aptitude*" OR "spatial visuali?ation skill*" OR "visual perception*" OR "space perception*" OR "spatial perception*" OR "psychomotor test*" OR "psychomotor abilit*" OR "psychomotor aptitude*" OR "psychomotor skill*" OR "perceptual abilit*" OR "perceptual aptitude*" OR "perceptual skill*"

S = Set.

Appendix 2. Excluded studies (n = 95)

References for excluded studies: [42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109,110,111,112,113,114,115,116,117,118,119,120,121,122,123,124,125,126,127,128,129,130,131,132,133,134,135,136]

Reasons for exclusion at the end of references (in parentheses):

1. Not in the field of technical skills in health care
2. Absence of an intervention
3. Absence of spatial abilities test scores before and after an intervention
4. Absence of spatial abilities test scores between intervention groups
5. Absence of spatial abilities test score
6. Lack of information for data extraction
7. Literature review

Appendix 3. Systematic review of included studies and results

Author(s), year	Design Sample size	Population: Participant, Country, Gender, Age	Intervention	Comparator	Spatial abilities test	Comparison between pre- and post-test scores (P)	Control group	Quality Assessment: SIGN-50[a]
Gibbons et al., 1986 [29]	Prospective cohort study N = 58	Residents in General Surgery University A (n = 42) University B (n = 16) Country: NI[b] Gender: NI Age: NI	Surgical training of nine months in 11 and more in others	None	Hidden Figures 32-item Pre-test Post-test after one year	Test-retest reliability r = 0.87	None	+
Hegarty et al., 2009 [30]	Prospective/ retrospective cohort study (Study 2) N = 206	First year (n = 79) and fourth year (n = 65) dentistry students and undergraduate psychology students (n = 62) United States of America	First-year Dental curriculum (one year)	None	Novel Object Cross-Section - 10-item - 5 min - one point for correct answer minus ¼ of incorrect answers - maximum possible score of 10 First year dentistry students (n = 79)	Novel Object Cross-Section Test: P = 0.07	Tooth Cross -Section Test: P < 0.001	+

(continued on next page)

(*continued*)

Author(s), year	Design Sample size	Population: Participant, Country, Gender, Age	Intervention	Comparator	Spatial abilities test	Comparison between pre- and post-test scores (P)	Control group	Quality Assessment: SIGN-50[a]
		80 females, 126 males Age: NI			Pre-test (August): 5.4 ± 2.1[c] Post-test (September): 5.8 ± 2.4 Tooth Cross-Section Test - 20 items - time: NI - one point for correct answer minus ¼ of incorrect answers - maximum possible score of 18 Undergraduate psychology students (n = 62) Pre-test (November): 7.1 ± 3.9 Post-test (September): 11.3 ± 4.3			
Clem et al., 2013 [31]	Prospective cohort study N = 79	Beginning sonography students United States of America Gender: NI Age: NI Drop out: 6	Two-semester learning period in abdominal sonography	None	Revised Minnesota Paper Form Board Test (RMPFBT) 65-question, 20- minute, paper and pencil, range of possible scores from 0 to 64 Pre-spatial tests scores Midwest university class 1: n = 11; 44.55 ± 5.429 Midwest university class 2: n = 13; 48.08 ± 5.722 Midwest university class 3: n = 19; 51.11 ± 7.745 Atlantic coast community college: n = 8; 52.25 ± 10.264 Midwestern community college: n = 11; 47.18 ± 8.424 Proprietary school n = 11; 40.18 ± 8.256 Post-spatial test scores: NI	N = 49 Midwest university class 3 Atlantic coast community college Midwestern community college Propriety school Effect size = 0.32 ($P < 0.05$)	None	+
Rengier et al., 2013 [32]	Prospective cohort study N = 27	Fourth and fifth-year medical students Germany Gender: NI Age: NI Drop out: 2	Hands-on radiology Course using interactive three-dimensional image post-processing software (analysis of cross-sectional imaging data and correlation of two-dimensional images with three-dimensional reconstructions) Seven seminars, each two hours long and held on a weekly basis covering musculoskeletal system, thorax, abdomen and pelvis, head and neck, central nervous system, and nuclear medicine	None	Cube perspective test – 32 questions Time: NI Maximum score of 16 N = 16 Corrects answers Pre-test: 10.1 ± 2.6 Post-test: 11.9 ± 2.4 Score including negative marking Pre-test: 7.9 ± 3.7 Post-test: 10.4 ± 3.2	Correct answers Improvement: 11.3% ($P < 0.001$) Score including negative marking Improvement: 15.6% ($P < 0.001$)	None	-

[a]SIGN-50, Scottish Intercollegiate Guidelines Network-50 (quality assessment); [b]NI, not identified; [c]mean ± standard deviation.

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