Is there a relationship between ultrasound scanning ability (sonography) and visuospatial perception or psychomotor ability?

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Abstract

Background: Competent sonography is thought to include a unique combination of skills not yet fully defined. This presents challenges when recruiting the correct people for training. Skills are thought to include visuospatial perception and psychomotor skills, but little is known about the relationship between these aptitudes and scanning ability. This feasibility study explored such relationships, to identify evaluation techniques which may improve selection and recruitment.

Methods: A sample of 30 experienced ultrasound practitioners and 30 trainees at commencement and on completion of training were administered eight tests.

Results: No significant relationships between experienced practitioners' or trainees' visuospatial abilities or psychomotor abilities and scanning abilities were found. Results demonstrated that two of the visuospatial perception tests were not influenced by training and therefore, may be measuring the innate skills of ultrasound practitioners. As ultrasound practitioners had not performed any of the tests previously, ranges of scores for each of the eight tests were established for this group. This included measures for psychomotor skills which added to the current body of knowledge for sonography.

Conclusions: Although no significant correlations were found between participants' visuospatial perception or psychomotor abilities and scanning ability, performance on the Obstetric Structured Assessment Test (combining all the skills required) pre-training gave the best indication of post-training scanning performance. The Obstetric Structured Assessment Test may prove a useful tool for initial assessment of potential trainees but abilities will require further investigation.

Keywords

Ultrasound practice, sonography, visuospatial perception, psychomotor ability

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Introduction

Currently, there is a UK wide shortage of sonographers.^{1–3} Demand for sonography services is increasing to meet the evolving needs of the population. This is a result of updated government health policies, government targets and delivery of several national screening programmes.⁴ This feasibility study sought to explore and address some of the challenges relating to student attrition and success on ultrasound training programmes. This was achieved through the exploration of potential evaluation techniques that could be implemented at the selection stage. This would provide evidence for

university admissions personnel and ultrasound departments to update their methods of selection.

Competent sonography incorporates a unique combination of skills perceived to include visuospatial perception (VSP) and psychomotor skills (PMS).⁵

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Currently, there is no clear definition or description of the skills; therefore, little is known about the relationship between VSP or PMS and scanning ability. This study sought to explore the possible relationships and assess the usefulness of employing the eight selected tests as pre-selection tools for sonography training. The hypothesis stated that there was a relationship between VSP, PMS and scanning ability. The aim was to identify and explore specific levels of VSP and PMS skills utilised in successful sonography.

Visuospatial ability refers to the human cognitive ability to generate, retain, retrieve and transform or manipulate mental models of a visual and spatial nature.⁶ Visuospatial ability embraces many cognitive functions including spatial ability, spatial cognition, spatial perception, spatial visualisation, visual object processing and visual acuity. Levels of visuospatial ability include high, intermediate and low levels and there are several tests available for testing each level.⁷ High and intermediate levels were tested in the current study because low-level tests were considered too simple and of little value in ultrasound practice.

PMS denote movements that are reasonably complex, the execution of which require at least a minimal amount of practice. A number of basic motor abilities underlie the performance of many routine activities and manual dexterity includes fine finger dexterity, arm wrist speed and aiming ability.⁸ Psychomotor abilities for ultrasound practitioners have not been investigated or documented in the past. Thoires and Coffee suggested that ultrasound practitioners develop sophisticated skills layered on knowledge of three-dimensional anatomy, together with knowledge of the physics of how sound interacts with human tissue. At the autonomous stage of skill acquisition, they use this knowledge to develop an eye-hand neural loop. The hand takes cues from real-time images on a monitor and makes adjustments to the transducer, which update the images continuously to acquire the desired image.⁹

There is great debate in current literature as to which of the multiple tests available for examining the varying levels of VSP and PMS skills are most appropriate. There is a dearth of research specifically regarding ultrasound practitioners. Studies involving other healthcare professionals, including surgeons, dentists and dental technicians were appraised. After detailed investigation and analysis of the skills utilised by ultrasound practitioners, eight tests were chosen for the current evaluation.

Materials and methods

A sample of 30 experienced sonographers and 30 trainees was administered eight tests. The trainees performed the tests at the commencement and at the end

of the ultrasound training course. A sample size of 30 for each group was deemed appropriate for an exploratory study. The minimum required for any between group analyses, in which statistical power can be considered robust is 20.¹⁰

The eight tests consisted of five VSP tests, two PMS tests and an Obstetric Structured Assessment Test (OSAT),¹¹ which evaluated scanning ability. The OSAT employed a fetal phantom model that the ultrasound practitioner attempted to scan.

The visuospatial abilities tests employed were as follows:

- The Gestalt Completion Test (GCT);
- The Snowy Picture Test, (SPT)¹² – Intermediate level, speed of closure;
- The Mental Rotation Test (MRT)¹³ – high level, space relations;
- The Surface Development Test (SDT)¹² – high level, visualisation;
- The Abstract Reasoning Test (ART)¹⁴ – high level, visual analysis, general reasoning skills.

Two psychomotor tests were employed. The Purdue Pegboard Test (PPT)¹⁵ measured dexterity for gross movement of arms, hands and fingers, and fingertip dexterity. The Zigzag Tracking test (ZZT)¹⁶ measured hand to eye coordination or speed and accuracy of hand movement. The test for scanning skills employed the OSAT, which measured time, error and quality.

The programme of work was divided into two stages. Stage 1, using a cross sectional design, involved collecting data for experienced ultrasound practitioners on one occasion. Stage 2, for trainees, used a longitudinal design to collect data at the beginning and on completion of the ultrasound course (approximately 12 months' duration).

Convenience sampling using only volunteers was employed. Ethical approval was obtained through the National Research Ethics Service (Ref. 10/S050501/62) and each of the three participating universities' ethics committees. The researcher obtained a certificate of achievement in Good Clinical Practice from the International Committee on Harmonisation Guidelines and the UK Clinical Trials Regulations 2009 (Certificate No: 15527-1-20460). A unique identification number was used to ensure participant anonymisation. Prior to participation, each applicant received an information sheet and signed a consent form.

Inclusion criteria for the experienced group were certificated ultrasound practitioners with a minimum of one year post-graduate experience. Participants were excluded from this group if they were experienced but held no formal ultrasound qualification. Trainees

(with a primary degree in either radiography or midwifery) were required to have less than six months' full-time (practical) experience in ultrasound. Trainees with more than six months' full-time practical experience and any volunteers who had performed any of the tests previously were excluded.

Data collected from the VSP tests were all numerical scores with known minimum and maximum values. In all cases, a higher score indicated higher ability levels. To calculate the score for the SDT, correct answers scored +1 and incorrect answers scored -0.5 (as indicated by the test instructions). Therefore, a negative score could be achieved if there were too many incorrect answers.

The PPT psychomotor test gave optimal results for the three trial administration (performing the tests three times and averaging the score) and high scores indicated better performance. As the sum of the right + left + both hands (arithmetic sum) score assessed gross hand to eye coordination and the assembly score assessed fine fingertip manual dexterity, these two scores were used to compare performance with the remainder of the tests employed. For the PPT, although a noted limitation of the study was small sample size, the range of scores expected from a group of experienced sonographers was established. There was no previous data available for this specific group.

The ZZT was designed for repeated administration. The test was scored in terms of performance time and error rate. The total time to complete the test was recorded to the nearest second. The error was calculated from points scored for deviations from the track or drawing through an obstacle in accordance with the test instructions. Three different versions of the test were performed; the first attempt was a practice. The average time and error scores for attempts two and three provided the total scores and were used in comparison against performance with the other tests. A short performance time with a low error score indicated good PMS.

At the commencement of this study, there were no easily available simulators to evaluate scanning ability. The OSAT was constructed for the purpose. The CIRS Model 068 Fetal Ultrasound Biometrics Phantom (CIRS, Norfolk, Virginia, USA) provided an objective test tool which included four measurements based on routine fetal screening measurements. These were biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC) and femur length (FL). BPD and FL are linear measurements and an ellipse method was used to measure HC and AC.

The phantom contained a symmetrical head with upper portion of the skull, right and left brain lobes and lateral and third ventricles, as shown in

Figure 1(a). The anatomical references were used to perform fetal head measurements. The BPD plane was measured from the outer surface of the proximal parietal bone to the inner surface of the distal parietal bone and HC was measured around the outside of the parietal bone (Figure 1(a)). For AC measurement, an umbilical marker indicated the correct plane for taking the measurement, which was measured around the skin line of the abdomen as shown in Figure 1(b). Femoral shafts with distal epiphysis were provided for FL measurements, which only included the long axis of the femur as shown in Figure 1(c). The sample images in Figure 1 taken by the researcher were used as reference images for the participants.

All participants were timed and their performance evaluated using three methods of scoring as summarised in Table 1. Better performance was indicated by a fast time with few errors and optimal quality scores (1 = optimal) as follows:

- Accuracy of measurement (against a known value); the recorded measurement minus the actual measurement gave an error score in millimetres;
- The time taken to achieve measurements in seconds;
- Overall quality of the image, plane acquired and measurement obtained, as assessed against a reference image and documented criteria.

Overall quality of the image was assessed by the researcher. This was performed during the examination on screen using subjective assessment. Factors scored included magnification, brightness, contrast, sector width and focal position.

The range of times and errors expected for completion of the tests for a group of experienced practitioners was established. For the trainees, performance was recorded pre- and post-training; this enabled the pre-training scores to be used as a baseline to assess changes in performance after training. For the experienced practitioners, the range of scores had to be established because there were no recorded data for any of the eight tests for this group for comparison with that from the trainee group.

Statistical analyses were performed using Statistical Package for Social Sciences (SPSS 21 for Windows). Descriptive statistics including mean, standard deviation, median and range were documented for each participant for each test (Table 2). Correlation analysis was used to evaluate whether good performance in one test predicted good performance in any of the other tests. Paired t-tests or Wilcoxon Signed-Rank Tests (depending on normality of distribution) were employed to look at the differences between pre- and post-training scores. In an attempt to evaluate whether

Figure 1. Fetal phantom sections for measurements. (a) Biparietal diameter (BPD) and head circumference (HC), (b) abdominal circumference (AC) and (c) femur length (FL).

Table 1. Summary of OSAT scoring system (quality 1 optimal, 4 sub-optimal)

OSAT Parameter	Time (second)	Actual (mm)	Error (mm)	Quality score
BPD		52		
HC		180		
AC		175		
FL		38		
Quality of overall image				1–4
Quality of image plane acquired				1–4
Quality of measurement				1–4

AC: abdominal circumference; BPD: biparietal diameter; FL: femur length; HC: head circumference; OSAT: Obstetric Structured Assessment Test.

Note Error (mm)=actual measurement minus achieved measurement.

any of the tests predicted the outcome of sonography training, a series of bivariate general linear models (GLMs) were run to look for any associations between scanning skills performance (OSAT time and error) and VSP or psychomotor test scores pre-training. The hypotheses were tested using the 5% level of significance.

Results

The range of scores for each of the eight tests for the experienced ultrasound practitioners is shown in Tables 2 and 3. A large number of experienced practitioners misinterpreted the HC border when measuring the HC. This raised concerns over the manufacturer's estimate of what they consider to be a correct circumferential measurement and therefore the HC measurements were excluded as an indicator of scanning performance. Although the average scores for both the experienced and trainee groups for all five of the VSP tests were poor, this is useful information for future researchers. The majority in both groups achieved less than 50% of the maximum score in both the MRT and the SDT, which measured high-level ability.

Table 2. Summary statistics for the experienced ultrasound practitioners for visuospatial perception and psychomotor tests (VSP $n = 29$ as one participant dropped out after the psychomotor tests)

	Possible range	Observed range	Median	Mean (SD)
VSP experienced ($n = 29$)				
SPT	0–24	8–22	13.0	12.7 (3.3)
MRT	0–20	0–13	7.0	6.6 (3.1)
SDT	–30–60	–2–59	28.0	28.6 (14.4)
GCT	0–20	6–18	12.0	12.4 (3.2)
ART	0–25	4–21	14.0	14.4 (3.8)
ZZT experienced ($n = 30$)				
ZZT Time (second)		37.0–115.5	66.7	68.8 (19.1)
ZZT Error (points)		0.5–27.5	7.7	9.1 (7.7)
PPT experienced ($n = 30$)				
Right hand (number achieved in 30 second)		14.3–19.3	17.0	16.9 (1.3)
Left hand (number achieved in 30 second)		14.0–19.7	16.0	16.2 (1.6)
Both hands (number achieved in 30 second)		8.3–16.3	11.7	12.1 (1.8)
Right + left + both hands (arithmetic sum)		38.3–55.0	44.7	45.6 (4.2)
Assembly (number achieved in 60 second)		26.7–48.7	34.7	36.1 (5.8)

Visuospatial perception tests (VSP): The Snowy Pictures Test (SPT); the Mental Rotation Test (MRT); the Surface Development Test (SDT); the Gestalt Completion Test (GCT); the Abstract Reasoning Test (ART). Psychomotor tests: the Zigzag Tracking test (ZZT); the Purdue Pegboard test (PPT).

Results for the trainees pre- and post-training suggested that three of the tests were influenced by sonography training. These were the intermediate level tests SPT ($p = 0.045$) and GCT ($p = 0.000$) and the high-level test SDT ($p = 0.003$) which showed significant improvement in scores after training. Performance has been influenced by sonography training and therefore they are not measuring the level of inherent skills. However, the ART and MRT results were not influenced by training; therefore, they may measure the innate skills of ultrasound practitioners and consequently may be useful in identifying those trainees who might take longer to train, or who may benefit from more intensive training and support.

Both trainees and experienced ultrasound practitioners had similar levels of visual analysis or general reasoning skills (concentration and interpretation skills) as measured by the ART. Therefore, this test might measure the level of inherent skills required. As there was a lack of correlation between the VSP tests

and post-training scanning performance, it was concluded that they were not appropriate tests in predicting the outcome of sonography training.

The ranges of scores were established for the group of experienced ultrasound practitioners. No relationships were found between psychomotor ability and sonography ability. However, again the findings may have been influenced by the small sample size. Post-training, the mean time taken to perform the ZZT reduced significantly ($p = 0.003$) but the average number of errors increased significantly ($p = 0.001$). Therefore, training reduced the time taken to perform the test at the expense of accuracy. The PPT tested gross hand to eye coordination and fine fingertip manual dexterity; scores increased significantly for the use of both right ($p = 0.005$) and left hand ($p = 0.001$) separately following training. The combined scores for right hand + left hand + both hands also increased significantly ($p < 0.001$), but there was no significant change in using both hands together or the assembly. It would

Table 3. Descriptive statistics for experienced ultrasound practitioners' performance of biparietal diameter, head circumference, abdominal circumference and femur length (measurement errors and performance times)

OSAT experienced (n = 30)	Mean (SD)	Median	Range
Error biparietal diameter (mm)	3.8 (1.2)	4.0	0.5–6.0
Time biparietal diameter (second)	32.8 (13.5)	32.8	12–73
Error head circumference (mm)	17.7 (8.2)	18.0	2–32.0
Time head circumference (second)	37.9 (12.7)	35.0	16–70
Error abdominal circumference (mm)	3.1 (2.3)	2.0	0–11.0
Time abdominal circumference (second)	48.8 (19.3)	46.5	24–103
Error femur length (mm)	1.5 (1.0)	1.0	0–4.0
Time femur length (second)	39.0 (17.7)	36.0	14–90

OSAT: Obstetric Structured Assessment Test.

appear that neither test is useful in isolation for assessing scanning skills, so perhaps the ZZT and PPT do not measure the required aptitude of hand to eye coordination and manual dexterity for performing sonography.

GLMs were employed to look for associations between scanning performance and performance on the VSP and PSM tests for the trainee group. Results demonstrated no associations between the VSP or PSM tests employed and post-training scanning ability, but there was association between pre- and post-training OSAT time and error scores. Performance on the OSAT pre-training gave the best indication of post-training performance.

Discussion and conclusions

The current methods of selection for sonography training may be enhanced by taking into consideration the special physical skills required to competently perform sonography. However, any change in the current system should be evidence based and acceptable to all stakeholders. Activities of this study were directed towards helping to answer the question: would identification of specific VSP and PMS required to successfully practice in sonography aid in the recruitment process of potential trainees?

A combination of skills is required when practicing sonography and this study sought to define these skills in terms of VSP by evaluating intermediate and high-level skills and PMS by evaluating gross and fine motor skills. However, there were discrepancies

between expected and observed outcomes. Results suggested the tests employed did not predict acquisition of sonography skills. The tests may not be appropriate for measurement of spatial aptitudes for sonography, which contradicts previous authors,¹⁷ but the finding may have been influenced by the small sample size. This may also be true for the PMS tests. There were no relationships between the VSP or PMS tests and the scanning ability tests (OSAT) identified.

There are numerous levels of VSP and PMS skills and multiple tests for examining them. It is difficult to know which are most appropriate but results suggest that the tests chosen for this study did not examine the correct levels of VSP or PMS required for sonography or they were not sensitive enough to differentiate the skill levels.

For this study the OSAT gave consistent assessments of clinical sonography performance using a well-defined protocol. Scanning skills performance on the OSAT before training gave an indication of post-training performance. A trainee who produced high scores before training also achieved the highest scores after training. Results indicated that it was a combination of skills rather than individual skills, which predicted successful performance. The OSAT in this study proved to be a useful tool for initial assessment of potential trainees. It is therefore advised, to enhance future studies, that all skills rather than individual skills are tested to aid the selection process. Recently, a number of simulators, such as the MedaPhor ScanTrainer Professional simulator (MedaPhor Ltd, Cardiff Medicentre, Cardiff,

UK) and the UltraSim simulator (Medsim Inc. Ft Lauderdale, USA) have been developed, which measure performance more objectively and may prove less time consuming to administer than the OSAT.

Employing a battery of tests in an attempt to quantify the range of inherent abilities of ultrasound practitioners was attempted. Out of the five VSP tests chosen, only two (MRT, ART) did not change with training; therefore, those are the tests more likely to measure the innate skills. As no correlation between the visuospatial tests and scanning ability was found, the researcher was unable to reject the null hypotheses. It would appear that, despite strong anecdotal evidence to the contrary, pre-training VSP skills have not been proven to predict post-training sonography competency. Although this initial research has tried to evaluate the visuospatial abilities that are relevant to specific sonography tasks, further work in this area is required. The challenge is to find VSP tests that measure constructs relevant to the level of skills required for sonography. Better understanding of the relationship between VSP and sonography skills acquisition may lead to better teaching models.

The PPT psychomotor test scores increased significantly for the use of both right and left hand separately following training. In the case of the assembly and both hands together, performance did not change significantly with training. Therefore, it was concluded that the assembly and both hands together components may be testing fine fingertip dexterity at an innate level required for sonography.

It must, however, be remembered that the abilities selected may not have represented all those important to the practice of sonography. The commercial tests may not have tested the sonography abilities as well as they could have. Regarding visual skills, it is more difficult to determine which ones are necessary for creating, understanding and interpreting sonograms. Both Berman¹⁸ and Clem et al.^{17,19} attempted to define and test them previously using visualisation.

This study achieved its aim of defining the range and average scores for the group of experienced ultrasound practitioners performing the chosen tests of spatial perception and PMS. This information added to the body of knowledge concerning sonography skills. There was little difference in the level of skills between trainees after training and experienced sonographers as judged by the chosen tests. Therefore, current selection processes may be good enough.

As far as the results of this study are concerned, performance on the OSAT pre-training gave the best indication of post-training performance. This may be a useful tool for initial assessment of potential trainees. Further studies using a larger sample would be required

before this could be validated or implemented. However, it would appear that successful sonography may rely on a combination of the previously mentioned skills, which remain to be comprehensively defined and, therefore, require further assessment.

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Guarantor

EC

Contributorship

EC researched literature and conceived the study. HG, EC and SH designed the manuscript. SH and EC did the data analysis. EC wrote the first draft and final version of the manuscript. All authors reviewed and approved the final version of the manuscript.

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