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Relationship Between Spatial Abilities, Mental Rotation and Functional Anatomy Learning

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Abstract. This study investigated the relationship between visuo-spatial representation, mental rotation (MR) and functional anatomy examination results. A total of 184 students completed the Group Embedded Figures Test (GEFT), Mental Rotation Test (MRT) and Gordon Test of Visual Imagery Control. The time spent on personal assignment was also considered. Men were found to score better than women on both GEFT and MRT, but the gender effect was limited to the interaction with MRT ability in the anatomy learning process. Significant correlations were found between visuo-spatial, MR abilities, and anatomy examination results. Data resulting from the best students' analyzes underscore the effect of high MR ability which may be considered reliable predictor of success in learning anatomy. The use of specific tests during learning sessions may facilitate the acquisition of anatomical knowledge.

Key words: field dependence–independence, functional anatomy, mental imagery, mental rotation, spatial abilities

Introduction

Mental imagery refers to the ability to form vivid mental representation of an object or a movement, by visualizing as many details as possible, and to preserve spatial and temporal characteristics of actual movement (Guillot and Collet, 2005a). The ability to form mental images may be estimated through both psychological and neurophysiological methods (for review, see Guillot and Collet, 2005b). Among subjects' abilities to manipulate mental images, mental rotation (MR) requires cognitive manipulation and spatial transformation of the imagined object and may be useful in spatial reasoning and problem-solving e.g. spatial orientation and mental navigation tasks using map displays (Gunzelmann and Anderson, 2004). Typical experimental designs requested subjects to judge whether pairs of visual 3D stimuli, presented from two different angles, were identical or not. Two objects that are identical (albeit rotated in a picture plane) or incongruent are thus commonly presented simultaneously in different orientations. Shepard and Metzler (1971) were the first to investigate such spatial visualization, using three-dimensional (3D) pictures composed of angular multiarmed cubes. They found that response time increased linearly with the degree of orientation difference between the two stimuli. The greater the difference, the longer it took to find that objects were either identical or mirror-image reversals of each other. Such results suggested that subjects formed a visual image of the object and rotated this image until congruence with the reference was reached. Similar findings were obtained by Shepard and Feng (1972), the time taken to carry out a specific MR task increasing linearly with rotation complexity. Recent studies have been devised to investigate the neural basis of MR (Vingerhoets et al., 2001, 2002; Parsons, 2003), the relationship between MR and motor processes (Wexler et al., 1998; Wohlschläger and Wohlschläger, 1998; Ozel et al., 2004), gender differences (Vandenberg and Kuse, 1978; Voyer and Bryden, 1990; Masters and Sanders, 1993; Peters et al., 1995; Jones et al., 2003; Karadi et al., 2003; Parsons et al., 2004) and other influencing factors upon MR abilities (Amorim and Stucchi, 1997; De'Sperati and Stucchi, 2000; Wraga et al., 2000; Carpenter and Proffitt, 2001; Kelley et al., 2001). To summarize, success in MR tasks involving non-significant objects, alpha-numeric characters or line drawings of significant objects, implies that subjects master an internal rotation, thus requiring re-orientation of the rotated objects in relation to each other. When considering the imagined spatial transformation of a body part, Parsons (1987) found that MR time of the hand to a given orientation was dependent on how awkward that orientation was. In this way, Parsons (1994) confirmed that MR of body segments followed the biomechanical constraints of actual movement. More recently, Petit et al. (2003) provided evidence that generation of the mental image of a moving body segment requires more time than that of an object of another nature, with no anatomical constraints. They concluded that the biomechanical constraints imposed on the movement should be considered attributes of the mental representation of body parts. Kosslyn et al. (1998) found inconsistencies when comparing MR of line drawings of hands to the mental rotation of 3D objects. This may be due to presentation of the hand as an isolated element, unattached to any articulation. Hands could therefore be considered objects identical to any 3D objects (Petit et al., 2003).

Functional anatomy teaching modules focus on introducing students to the study of the human musculoskeletal system, to analyze movement and isolate specific muscle groups. Students are instructed on how space is organized to describe anatomical structures: (i) with reference to anterior-posterior, vertical and lateral planes, on the one hand, and (ii) with reference to horizontal, coronal and sagittal planes, on the other. They are therefore commonly requested to rotate the skeleton mentally in different planes and to view muscles, insertions and trajectories from static representation (Figure 1) and, during contraction, from dynamic representation of any angle (Thiriet, 1982, p. 164). Visualization of both static and dynamic functioning of the musculoskeletal system with emphasis on the mechanical aspect of human movement, postural assessment and joint measurement, is thus usually required.

Such spatial representation calls upon MR ability. Anatomical structures may be imagined isolated elements and therefore rotated in different planes. Another way is to consider anatomical structures resembling 2D or 3D objects. Such a procedure leads students to identify and disembed simple forms from the background, and then to extract them from more complex figures. According to the influence of anatomical and biomechanical constraints on MR of attached body segments (Parsons, 1994; Petit et al., 2003), comparison between musculoskeletal structures and usual objects may enhance the ability to form a mental image and then perform MR. Thus, being efficient in learning functional anatomy may require accurate ‘‘visualization of spatial reasoning’’ and the ability to use mental imagery associated or otherwise with MR. Such a relationship will suggest that students with high visuo-spatial, mental imagery and MR abilities would obtain

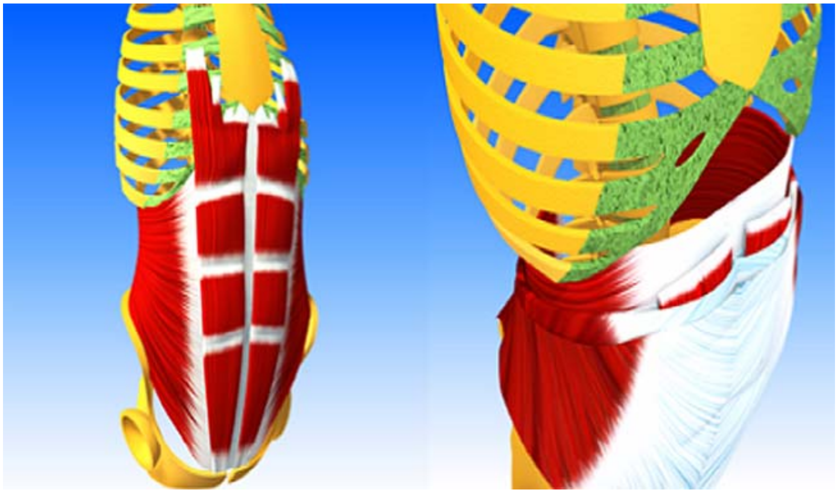

Figure 1. Different views of abdominal muscles. To understand that the abdominal muscles are composed of several covering muscles (the *Rectus Abdominis muscles, linae Transversae, Obliquus Externus* and *Obliquus Internus*) on the one hand, that they sit on the front and sides of the lower half of the torso, originate from the rib cage and attach along the pelvis on the other hand, students need several views from different angles. Such a mental representation may be useful to indicate if the *Obliquus Externus* is the outermost muscle covering the side of the abdomen and to describe the direction of its fibers.

better results in anatomy examination. Keehner et al. (2004a, b) explored such a relationship, by examining how it was modulated, using interactive computer visualizations. Subjects were required to draw cross-sections of a fictitious, anatomy-like structure while actively manipulating or passively watching a dynamic, rotating 3D computer visualization of the structure. A correlation between spatial abilities and performance was found, suggesting that students used a range of strategies including MR. Similar results were also obtained by Garg et al. (1999, 2001) and Wanzel et al. (2002). However, relationships between MR abilities and human anatomy learning have received too little attention, and still remain a working hypothesis awaiting experimental investigation.

This study was therefore devised to investigate relationships between visuo-spatial representation, mental imagery, MR and functional anatomy examination results. First, Witkin (1950) proposed a continuum of perceptual styles ranging from field-dependence to field-independence. Field-independent subjects tend to disembed objects from their background more easily. They generally support internal referents and show high ability to use restructuring skills. Students with learning disabilities are believed to be more field-dependent than those without learning disabilities (Huang and Chao, 2000). The Group Embedded Figures Test (Oltman et al., 1971) is often used to evaluate field dependence–independence (Guillot and Collet, 2004; Guillot et al., 2004). As functional anatomy requires visualization of spatial reasoning and re-organization of spatial representations, our first hypothesis is that students who performed best in the anatomy examination are expected to be more field-independent than those who obtained a poor score. Our second hypothesis is based upon the ability to form a mental image, which can be estimated through several psychological tests. As functional anatomy requires visualization of muscle origins and insertions in different planes as well as length modifications during dynamic contraction, two specific dimensions of mental imagery accuracy are needed: vividness and control of the imagined object. These can be evaluated through the Visual Imagery Control Test (Gordon, 1949), the most widely used version being proposed by Richardson (1969). As pointed out in the literature (White and Ashton, 1977; Perez-Fabello and Campos, 2004), this test comprises four factors (movement, misfortune, color and stationarity). A relationship between the highest test scores and the best results in anatomy examination is expected. Our third hypothesis is that the ability to rotate the object mentally is needed, thus leading to a positive correlation between the MR test (Vandenberg and Kuse, 1978) and the examination result. These hypotheses may also depend on the nature of the examination questions. Thus, expected relationships will be restricted to questions requiring specific visuo-spatial abilities only and will be modulated by consideration of each student's personal self-investment. It is thus expected that specific mental imagery and/or MR abilities could be helpful during functional anatomy learning modules.

Methods

Participants

A total of 184 students (130 men and 54 women, mean age 19.34 years, range 17–23 years, SD = 1.17) took part in the experiment after providing their informed consent. Experimental procedures were approved by the local research ethics board. All participants were students enrolled on a program of lectures at Claude Bernard University, Lyon. They had normal or corrected-to-normal vision and none had any specific experience in the field of spatial cognition. Participants were not made aware of the purposes or hypotheses of the experiment until after test completion.

Procedure

At the beginning of the functional anatomy learning module, participants completed three paper-and-pencil tests in a quiet room, each being related to spatial visualisation, MR and mental imagery abilities. These tests were provided simultaneously to 6 groups of around 30 students who completed the tests in a counterbalanced order.

The Group Embedded Figures Test (GEFT – Oltman et al., 1971), based upon the perception of 18 simple forms, was used to evaluate the degree of field dependence–independence. This requires recognition of figures previously presented by the experimenter within a large complex frame and integrating many other shapes. The test was in three sections: seven practice items, nine test-items and nine difficult test-items. The practice items were completed within a 2-min period and each other test section was performed within 5 min. The score was based on the number of simple forms correctly identified during the second and third sections and ranged from 0 to 18 (the highest scores being related to greater field independence). Figure 2 shows how the ability to extract a simple form from a more complex structure may be generalized to anatomical designs.

Participants also completed the Vandenberg and Kuse (1978) Mental Rotation Test (MRT), which was constructed from the 3D items used in the chronometric study by Shepard and Metzler (1971). A reference item was presented on the left, while four other figures were placed on the right of the paper. Two figures from the four presented were systematically similar to the reference, albeit rotated around one axis in steps of 20° (Hochberg and Gellman, 1977). These two remaining 3D objects, identical to the reference, were to be found and crossed. Participants were told to make figures rotate mentally with a view to making them match the reference whenever possible.

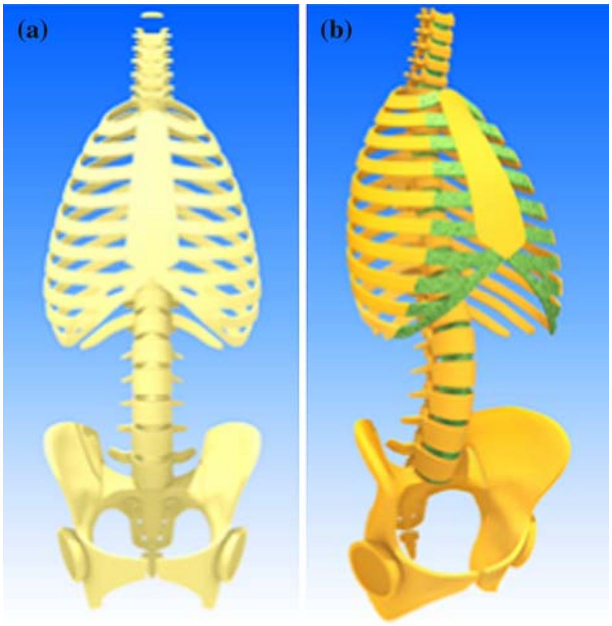

Figure 2. Relationship between the ability to recognize a simple anatomical form within a more complex frame. "*The anterior surface of the costal cartilages is convex and looks forward and upward, each costal cartilage presenting 2 surfaces, 2 borders and 2 extremities*". To indicate whether such an affirmation is true or false, the student may have to identify and disembed the "costal cartilage form" from the background of the complex figure (a), as shown by figure (b)

The test was made up of 24 items, the reference figure changing on each line. The practice items were completed within a 6-min period. As in the study by Peters et al. (1995), a scoring method that discouraged guessing was used, a single point being given if and only if both correct stimuli were identified. This method was favoured by Vandenberg and Kuse (1978). Scores thus ranged for each individual from 0 to 24. Participants were discouraged from using a strategy that would lead to a reduction in response time at the expense of the number of correct responses. The expected relationship between MR and the ability to visualize specific anatomy structures from all angles is illustrated in Figure 3.

The third test was devised to estimate students' visual imagery ability and control of mental images. The Gordon Test of Visual Imagery Control (GTVIC – Richardson, 1969) comprises 12 items through which subjects were required to imagine a motor car in different situations and to rate the accuracy of each mental image on a three-step scale. The score is dependent on whether they had trouble imagining the object in various different colors, positions and states of motion. Four specific factors were identified (Perez-Fabello and

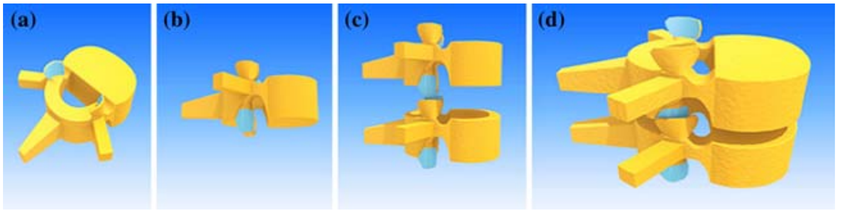

Figure 3. Relationship between MR and anatomy. "*The inferior articular processes project downward from the junctions of pedicles and laminae. Their facets are convex, directed forward and lateralward, and are embraced by the superior processes of the subadjacent vertebra*". When the student is required to indicate whether such an affirmation is true or false, MR of the initial figure (a) is needed and helpful.

Campos, 2004): movement, misfortune, color and stationarity. Scores were from 0 to 24, higher scores indicating better ability to form and control mental images.

The anatomy examination required students to complete a multiple choice test made up of 220 propositions within a 60-min period. For each item, four objectives were proposed and students had to indicate whether each of these was right or wrong. The number of correct responses was taken as a reference in place of the examination grade, to clarify the interaction between the correct response and the item category.

Before the examination, the anatomy-learning program consisted of 14 lecture hours and 14 hands-on training hours, during which students manipulated human skeletons and worked from skeletal and muscular overviews. To evaluate the effect of individual preparation, students answered a comprehensive questionnaire evaluating the time spent on the functional anatomy assignment. A total of 148 students completed this questionnaire after the experiment.

Data analysis

The analysis of variance was used to compare men and women in psychological tests and functional anatomy examination results. The Pearson's Correlation test was used to assess the linear correlation between psychological test scores and functional anatomy results, with regard to the correlations referring to specific question types. A multiple analysis of covariance (MANCOVA) was performed to determine the relationship between the anatomy examination result and the MRT, GEFT and GTVIC scores according to gender. Firstly, a model allowing all possible interactions between gender and the three independent variables (MRT, GEFT and GTVIC scores) was fitted. Then, the interactions and the main effects that were not significant were excluded in order to keep the most adequate and simple model. Residual diagnostic plot and introduction of second degree terms were used to check the adequacy of the model. The results are presented as such: mean (standard deviation values) and the alpha level was set at 0.05.

Finally, a subgroup analysis was performed to check whether the relationship between spatial abilities and anatomy competence may specifically differ between the very best and "poor" students. The selection of the subgroups was done by using the method described in the paper by Goss et al. (1986), i.e. at least 1 SD above/below the mean score at the anatomy examination.

Results

Psychological tests

GEFT scores were computed from the nine items of each section. The mean score was 13.63 (SD = 3.85), the lowest and highest scores being 0 and 18, respectively. GEFT scores were significantly different across genders ($F_{1,182} = 4.03$, $p < 0.05$), lower scores being obtained by women (12.7, SD = 4.21) compared with male scores (13.9, SD = 3.69).

The mean MRT score was 9.64 (SD = 3.97), the lowest and highest scores being 2 and 22, respectively. Significantly different scores were found when women and men were compared ($F_{1,182} = 17.29$, $p < 0.0001$), mean scores being 7.8 (SD = 3.69) and 10.38 (SD = 3.89), respectively.

The mean GTVIC score was 20.76 (SD = 3.49), the lowest and highest scores being 6 and 24, respectively. With regard to the four factors of this test (movement, misfortune, color and stationarity), respective mean scores (SD) were 8.35 (1.75), 6.91 (1.47), 3.66 (0.83) and 3.69 (0.86). No significant difference ($F_{1,182} = 0.09$, $p > 0.05$, NS) was found between women (20.78, SD = 3.45) and men (20.61, SD = 3.53) either in mean or in specific factor scores ($p > 0.05$, NS).

Mean GTVIC scores were not correlated with MRT scores ($r = -0.07$, $p > 0.05$, NS) or with GEFT scores ($r = 0.07$, $p > 0.05$, NS). Conversely, a low positive correlation ($r = 0.22$, $p < 0.01$) was found between MRT and GEFT scores.

Anatomy examination results

From the 220 questions, the number of correct responses was considered the score for each student. The mean of correct answers was 159.67 (SD = 18.67), the lowest and largest number of correct responses being 114 and 202, respectively. Significantly different scores were found when comparing men and women ($F_{1,182} = 11.32$, $p < 0.001$), mean scores being 162.33 (SD = 17.17) and 153.28 (SD = 20.67), respectively. Psychological

Table I. Gender comparisons

Variable	Men & Women (*n* = 184)		Men (*n* = 130)		Women (*n* = 54)		*F*(1,182)	*p*
	Mean	S.D.	Mean	S.D.	Mean	S.D.		
GEFT score	13.63	3.85	13.93	3.50	12.72	4.21	4.03	$p < 0.05$
MRT score	9.70	4.07	10.38	3.89	7.80	3.69	17.29	$p < 0.0001$
GTVIC score	20.76	3.49	20.78	3.45	20.61	3.53	0.09	$p = 0.8$ NS
Anatomy score	159.67	18.67	162.33	17.17	153.28	20.67	11.32	$p < 0.0001$

Gender performance differences in the GEFT, MRT and anatomy examination were found to favor men significantly. Conversely, no difference was observed when considering GTVIC performance.
Note: GEFT – Group Embedded Figures Test; MRT – Mental Rotation Test; GTVIG – Gordon Test of Visual Imagery Questionnaire; NS – non-significant.

test results and mean correct responses in the examination are summarized in Table I.

Inter-correlations

First, a MANCOVA model allowing all possible interactions between the gender and the three independent variables (MRT, GEFT and GTVIC scores) was performed. The interactions GTVIC*GENDER ($F_{1,176} = 0.17$, $p > 0.05$, NS) and GEFT*GENDER ($F_{1,176} = 2.73$, $p > 0.05$, NS) were not significant and therefore not taken into consideration. Similarly, the GTVIC main effect did not reach significance ($F_{1,178} = 0.05$, $p > 0.05$, NS) and was excluded from the model. We thus fitted a new simple model (Table II) using the significant interaction MRT*GENDER ($F_{1,179} = 7.13$, $p < 0.01$) and the

Table II. GEFT and MRT*GENDER effect

Estimate	SE	*T*	Value	*p*
GEFT	1.78	0.33	5.39	<0.001
MRT	2.12	0.61	3.46	<0.001
GENDER	21.09	6.67	3.16	<0.01
MRT*GENDER	−1.9	0.71	−2.67	<0.01

The model used the significant interaction MRT*GENDER and the significant GEFT main effect to assess the relative contributions of the psychological tests to the anatomy competence.
Note: GEFT – Group Embedded Figures Test; MRT – Mental Rotation Test; GTVIG – Gordon Test of Visual Imagery Questionnaire; SE – Standard Error.

significant GEFT main effect ($F_{1,179} = 29$, $p < 0.001$). The assessment of several residuals diagnostic plots revealed that the data reasonably met the usual assumptions of normality and homoscedasticity. Moreover, the tentative introductions of second-degree terms for the GEFT, GTVIC and MRT scores or those of interaction terms between these three variables (in order to improve the model) systematically appeared to be non-significant. The chosen model that only includes the MRT*GENDER interaction and the GEFT main effect seems thus adequate. The corresponding multiple correlation coefficient (r^2) was 26%. The relationships can therefore be summarized by the following equations:

For women, Anatomy score = 114 + 1.8*GEFT score + 2.1*MRT score.

For men, Anatomy score = 135.1 + 1.8*GEFT score + 0.2*MRT score.

The strong relationship between the anatomy examination result and the GEFT score, therefore, does not depend on gender. Conversely, the relationship between the anatomy result and the MRT score is very strong for women but not for men. For example, using a similar GEFT score equal to 10 and a similar MRT score equal to 0, the final anatomy examination result would be equal to 153 for a man vs. 132 for a woman. However, for a similar GEFT score equal to 10, but a MRT score equal to 20, the final anatomy examination result would be equal to 157 for a man vs. 174 for a woman.

Students were divided into three groups according to their examination results (at least 1 SD above/below the mean score): more than 180 correct responses (Group 1), between 140 and 180 correct responses (Group 2) and fewer than 140 correct responses (Group 3). When considering the best students (Group 1, $n = 31$), a strong relationship was found between MRT scores and examination results ($r = -0.64$, $p < 0.001$ – Figure 4). Conversely, such a relationship was not observed in the two groups of students who performed less well (Groups 2, $n = 37$ and Group 3, $n = 116$), while a significant correlation was found between examination results and GEFT scores ($r = -0.47$, $p < 0.01$ and $r = -0.35$, $p < 0.001$).

The comprehensive questionnaire devised to evaluate the time spent on the functional anatomy assignment indicated that the amount of individual preparation ranged from 2 to 60 h. Self-reported evaluation of personal work was slightly correlated with the number of correct responses at the test ($r = -0.21$, $p < 0.01$). When considering each group separately, there was no correlation between these two variables ($p > 0.05$, NS). Furthermore, although the best students devoted more time to the functional anatomy assignment than others, the tendency was not significant ($p = 0.09$, NS), with a high inter-subject variability, whereas the number of correct responses differed ($p < 0.001$), as shown in Figure 5.

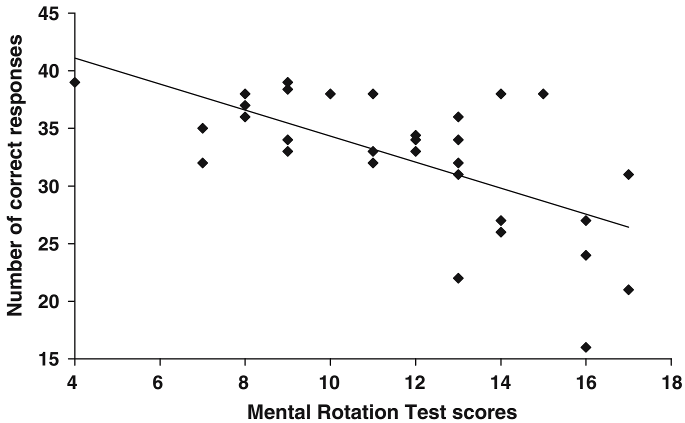

Figure 4. Magnitude of the number of correct responses as a function of the MRT score during anatomy examination. The magnitude of the number of correct responses increased when students obtained a high MRT score. Performing well was therefore related to high MR ability.

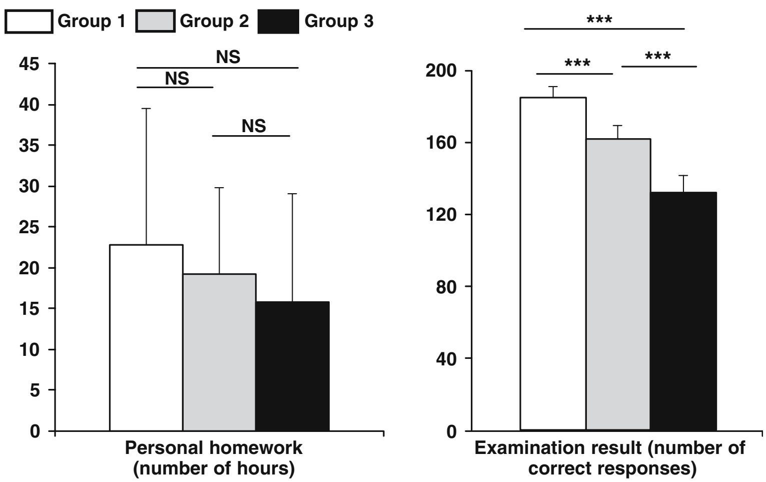

Figure 5. Functional anatomy assignment and examination result. Students were divided into three groups according to the number of correct responses ($n > 180$, $140 < n < 180$, $n < 140$). The time spent working on functional anatomy at home did not differ among groups (although best students showed a tendency to spend more time than the worst, $p = 0.09$, MS). MS – marginally significant. This may be explained by the high inter-subject variability.

Discussion

The MANCOVA provided evidence of a strong relationship between spatial abilities evaluated through MRT and GEFT tests and anatomy competence. Such tests had already been shown to be correlated with human orientation

(Richards et al., 2002–2003). With regard to spatial anatomy learning, this result is in keeping with the studies by Garg et al. (1999, 2001) and Keehner et al. (2004a, b), and reinforces the hypothesis suggesting that students with high visuo-spatial and MR abilities are favoured. Wanzel et al. (2002) also provided evidence that high-level visuo-spatial abilities were related to the quality of the results in a surgical procedure. Therefore, as predicted, field-independence and the ability to rotate the body segment mentally may thus be considered independently influencing factors of performance in anatomy learning. Conversely, the hypothesis stating that the ability to generate static mental images of a body segment in a specific orientation may be correlated with anatomy competence was not supported, as no correlation was found between the number of correct answers and the GTVIC score. These results also strongly support the recent findings by Black (2005), who found a relationship between earth science concept understandings and both a MR test (the Purvue Visualization of Rotation Tests, Guay, 1977) and the GEFT scores. When considering the classification of the three types of spatial abilities proposed by Linn and Petersen (1985) (MR, spatial perception and spatial visualisation), the present results therefore, agree with their result that both MR and spatial perception (including the focus on disembedding and overcoming distracting cues, Linn & Petersen, 1985, p. 1482) are the most reliable predictors of anatomy competence. Indeed, we can assume that spatial perception and visualization of a body segment is an advantage since students are able to represent insertions and structures mentally from several angles, which automatically requires MR of the image. When considering the best students who obtained more correct responses, a strong relationship was found between MRT scores and the examination results (Figure 4). Such a finding may indicate that while general MR and spatial abilities help students to learn spatial anatomy, specific MR ability is the most discriminating factor in good performance. Such a relationship may be explained by the nature of the test: from the three tests undergone, the MRT was the only one requiring subjects to manipulate 3D items. Performing MR of a body segment or an isolated muscle may similarly require students to visualize in a 3D orientation. The best students were therefore believed to transfer their MR ability to specific MR of a body segment before answering, while other students performed less well.

Although the study did not specifically focused on gender differences, a gender effect was observed, men performing MR better than women and being less field-dependent. This finding complies with traditionally reported gender effects, slightly lower female scores being commonly reported (Witkin et al., 1971; Cano and Marquez, 1995; De Andres et al., 2004), due to multifaceted factors. As functional anatomy requires students to form and manipulate mental representation of a cross-section of anatomy-like structures incorporating some spatial characteristics, women were expected having greater difficulty in generating and manipulating such mental images, due to less spatial ability, as observed in numerous human cognition experiments (for review, see Jones et al., 2003). In this study, the analysis revealed only a gender difference through the MRT*GENDER interaction. Such a result in anatomy learning therefore questions the effect of the well-established simple gender differences in both MR and field dependence–independence tasks. When considering potential gender-specific cortical activation patterns for MR of hands and tools, Seurinck et al. (2004) found only slight differences, men and women using very similar motor strategies during egocentric MR. Finally, whatever the gender, it may be hypothesized that the anatomy examination did not only evaluate the acquisition and retention of the functional anatomy knowledge, but also students' visuo-spatial and MR abilities. Furthermore, the better results of male students in the functional anatomy examination contrast with lesser success in their academic education in comparison with women; this would seem to confirm that an independent external factor may have influenced performance.

Although self-reported evaluation of personal preparation was only slightly correlated with the number of correct responses, data from each group provided evidence that there was no clear relationship between the time spent on the functional anatomy assignment and the examination result. More specifically, personal work did not statistically differ among students, whatever the examination result. Although this may be explained by the high inter-subject variability (Figure 5), such a finding would seem to indicate that preparation may not be considered a sufficient factor to succeed the examination and that the differences that have been pointed out may also depend on an external factor. Present findings however do not exclude a potential influence of differences in subjects' abilities to deal with stressful situations such as examination (multiple choice test).

The opportunity to use spatial ability and MR tests as part of a battery to assess a student's aptitude for success in anatomy is worth consideration. Such a relationship has frequently been discussed in medical education and surgery (Rochford, 1985; Salthouse, 1992; Gilligan et al., 1999; Wanzel et al., 2002; Keehner et al., 2004a, b). Specific spatial and MR training (e.g. by using computerized representations of 3D structures and/or MR tests) may help students in acquiring anatomical knowledge. Although Heil et al. (1998) found that MR skills may be transferred to an identical condition only, recent data challenge this hypothesis, suggesting that transfer of rotation skills may also occur with new stimuli. Wraga et al. (2003) provided evidence that motor strategies could be transferred implicitly from a task involving egocentric transformations to another task that does not. Similarly, Pavlik and Anderson (2002) found transfer of rotation between 3D figures. However, the transfer from a 2D or 3D figure task to another task involving egocentric transformations (such as MR of a complex anatomical structure) has received too little attention, cerebral structures activated during egocentric perspective and object-based spatial transformations being somewhat different (Kosslyn et al. 1998; Zacks et al., 1999). Furthermore, studies with brain-damaged patients suggest that the ability to rotate a body part may be functionally separated from the ability to rotate an externally based-object, a dissociation between deficits of the two functions being reported (Rumiati et al., 2001; Sirigu and Duhamel, 2001; Tomasino et al., 2003). However, by investigating the effects of virtual reality, Tracey and Lathan (2001) showed that subjects with poor spatial abilities transferred positively from a simulator-based training task to a similar real-world robotic operation task. A similar positive transfer may be expected from a neutral MR task involving 3D items (e.g. those used by Shepard and Metzler, 1971) to another MR task involving body segment and complex anatomical structure transformations. Indeed, as a correlation was found between the best students' results and MRT scores, it can be supposed that these students transferred their ability to a task involving egocentric transformations. At this time, this still nevertheless remains a working hypothesis awaiting further experimental investigation.

Conclusion

To summarize, men scored better than women in GEFT and MRT, but the gender effect was limited to the interaction with MRT ability in the anatomy learning process. The correlations found between visual spatial and MR abilities and anatomy examination results underscore the advantage of students with high spatial abilities. Such abilities could therefore be considered reliable forecasters of success in acquiring anatomy, and the use of specific tests during learning sessions may facilitate the acquisition of anatomical knowledge. Data resulting from the personal preparation analysis reinforced this hypothesis. As suggested by Wanzel et al. (2002), such predictive tests could affect technical skills learning and training in various scientific (e.g. architecture and design) and medical disciplines, and help to identify students who might need supplementary teaching modules.

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