Strategies in Virtual Anatomical Learning

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Abstract

The present study examined the use of verbal-analytical and visual-spatial strategies in anatomical learning. An interference paradigm and a questionnaire were used to identify these strategies in a test that was used to assess knowledge that participants had acquired after studying two computerized 3D models of human anatomy. Relations of cognitive abilities with strategy use were also examined. Individual differences in effects of two interference tasks suggest that under single task conditions individual differences in strategies existed. However, these strategies were neither pure verbal-analytical, nor pure visual-spatial as the results indicate that the strategy that was used relied on both verbal-analytical and visual-spatial working memory resources. Although both resources were required, the latter was thought to be the most important of the two. The extent to which participants relied on either resource was suggested to be mediated by their cognitive abilities.

Introduction

Acquiring knowledge of human anatomy is a crucial part of becoming a medical practitioner. Several different methods such as cadaver dissections, illustrated texts, models, and computer applications are used to teach anatomy to medical students. Although these methods differ in several aspects, all have the purpose of providing students with opportunities to acquire an accurate mental representation of human anatomy. The introduction of non-invasive imaging techniques in diagnosis and minimally-invasive techniques in surgery has made it even more important to have an accurate mental representation. With these techniques, the anatomy of a patient is often viewed from unfamiliar angles and in 2-D only. Thus, in order to make a correct diagnosis or perform successful surgery, practitioners have to manipulate their mental representation of the anatomy to compare it with the information at hand.

It is of interest then to know how anatomy is mentally represented and how this representation is used. In his dual coding theory of mental representations, Paivio (1986) argues that two separate cognitive subsystems exist for both the representation and processing of information. One subsystem is specialized for verbal information and one for nonverbal information. He further argues that these subsystems can be active alone or in parallel, and that interconnections between both subsystems are possible. Wickens (1986), in his multiple resource model, distinguishes between verbal and spatial processing codes, which play a role in perception as well as cognition. In Baddeley's model of working memory (2003), separate systems are involved in the storage of verbal and visual-spatial information. Thus, these models all suggest that information can be mentally represented and processed in both verbal and visual-spatial ways.

Strategies

Verbal and visual-spatial ways of mentally representing and processing information are thought to play a role in visual-spatial tasks through the employment of different strategies. In line with the verbal and visual-spatial nature of mental representations, these strategies can generally be arranged on a continuum between verbal-analytical and holistic visual-spatial strategies (Glück & Fitting, 2003; Boulter & Kirby, 2001; Cooper, 1982; Kyllonen, Lohman, & Snow, 1984). When employing a holistic visual-spatial strategy, individuals are thought to visualize the required manipulation as a whole. In contrast, individuals are thought not to rely on visualization when a verbal-analytical strategy is employed. Typical of this strategy is that the required manipulation is thought to be performed on parts of the stimuli in a sequential manner, and is accompanied by internal speech (Kyllonen, Lohman, & Snow, 1984; Boulter & Kirby, 2001). Between these two strategies that make up the extremes of the continuum, intermediate strategies that combine characteristics of both strategies exist. One such strategy is that of sequentially visualizing parts of the required manipulation (Boulter & Kirby, 2001; Glück & Fitting, 2003).

Strategies and performance

Knowledge of verbal-analytical and visual-spatial strategies is important as strategy use has been found to be related to performance on visual-spatial tasks. Cooper (1982) examined how mental representations were compared with externally presented visual information. Participants had to decide whether a visually presented stimulus was the same or not as an earlier presented stimulus. Two distinct patterns of performance were observed that were thought to be related to the use of different strategies. Participants whose reaction times were not affected by differences in similarity were thought to have been using a holistic strategy, while participants whose reaction times dropped with decreasing similarity were thought to have been using an analytical strategy. When deciding whether the two stimuli were the same or not, no differences were found. However, when participants were asked to identify the part of the second stimulus that was different, those who were thought to have been using a holistic strategy were less accurate. Contrary to this, results of a study by Schultz (1991) showed that self-reported strategy use correlated significantly with mental rotation and spatial orientation accuracy, with the use of a visual-spatial strategy being associated with better performance. This was true even after effects of other variables possibly influencing performance, such as sex and handedness, were cancelled out. Wanzel, Anastakis, McAndrews, Grober, Sidhu, Taylor, Mikulis, and Hamstra (2007) also suggested that the use of a visual-spatial strategy was related to mental rotation accuracy. In a fMRI study, they found a positive correlation between mental rotation accuracy and the amount of activation in cortical regions that were associated with visual imagery and motion processing. They suggested that this was the result of a visual-spatial strategy used by best performing participants. Summarizing the results from these studies seems difficult at first. However, when the relations of strategy use with characteristics of both tasks and individuals are considered, a clearer picture emerges.

Task characteristics

The speed advantage of a visual-spatial over a verbal-analytical strategy found by Cooper (1982) is not surprising considering the sequential nature of a verbal-analytical strategy as opposed to the parallel nature of a visual-spatial strategy. However, the advantage of a visual-spatial strategy over a verbal-analytical one on accuracy in the studies of Schultz (1991) and Wanzel et al. (2007) seems in contrast with the results of Cooper (1982). Cooper found no difference in accuracy between the two strategies, and neither a negative correlation between the use of a visual-spatial strategy and accuracy. The differences between these studies lie in the task that was used. Cooper used a visual comparison task, while Wanzel et al. (2007) used a mental rotation test and Schultz (1991) both a mental rotation test and spatial orientation test. Thus, task characteristics play a role in determining which strategy leads to the best performance. Difficulty is one of the task characteristics that has been found to be related to strategy use in other studies. Kyllonen, Lohman, and Snow (1984) used different instruction videos in an attempt to train participants to use either a visual-spatial or a verbal-analytical strategy, in order to improve their performance on a paper folding test. They suggested that verbal-analytical strategies were most effective when solving the more difficult items, while a visual-spatial strategy was more successful for the easiest items. Stimulus complexity is another task characteristic found to be related to strategy use. Glück and Fitting (2003) argued that use of holistic strategies is related to low stimulus complexity, while use of either holistic or verbal-analytical strategies is related to intermediate levels of stimulus complexity. High levels of stimulus complexity are argued to be related to the use of intermediate strategies, which incorporate features of both holistic and analytical strategies. Thus, task characteristics such as difficulty and stimulus complexity are thought to be related to strategy use.

Individual characteristics

In addition to task characteristics, individual differences may also be related to strategy use. The most likely difference would be that of cognitive abilities. Given the distinction between visual-spatial and verbal-analytical strategies, it is interesting to examine whether visual-spatial and verbal-analytical abilities of the participants are related to the strategy that is used. Individuals high in visual-spatial ability relative to verbal-analytical ability may be more likely to use a visual-spatial or primarily visual-spatial strategy, as such a strategy would be expected to be more successful for them. Likewise, it could be argued that individuals high in verbal-analytical relative to visual-spatial ability may be more likely to use a strategy that would be verbal-analytical or primarily verbal-analytical. Kyllonen, Lohman, and Snow

(1984) used different instruction videos in an attempt to train participants to use either a visual-spatial or a verbal-analytical strategy, in order to improve their performance on a paper folding test. They also subjected their participants to a number of cognitive ability tests, which included visual-spatial, analytical, verbal, and memory abilities. They combined these tests to form one index of fluid-analytic and visualization ability, and one index of verbal-crystallized ability. Their results showed several effects of training, with the most pronounced effect being that participants with a high verbal-crystallized ability index score and a low fluid-analytical and visualization ability score performed best after receiving the analytic strategy training. Although other cognitive abilities were assessed in the Kyllonen et al. study than the verbal-analytical and visual-spatial abilities in the present study, the results show that cognitive abilities are related to differences in visual-spatial and verbal-analytical strategy use.

Another cognitive ability that may be related to strategy use is that of working memory span. Baddeley’s model of working memory (2003) distinguishes between separate storage components for verbal and visual-spatial information. Similar to verbal-analytical and visual-spatial ability, it can be argued that participants with a large visual-spatial relative to verbal working memory span may be more likely to use a visual-spatial or primarily visual-spatial strategy, as this would be expected to be a more successful strategy for these participants. Likewise, participants with a large verbal working memory span may be more likely to use a strategy that would be verbal-analytical or primarily verbal-analytical.

While in the domain of anatomical learning little is known about strategy use, cognitive abilities, in particular visual-spatial ability, have been found to play an important role in predicting anatomical learning success. Wanzel, Hamstra, Anastakis, Matsumoto, and Cusimano (2002) found a positive correlation between visual-spatial ability and performance on tasks related to anatomical learning, such as the learning of spatially-complex surgical procedures. Garg, Norman, and Sperotable (2001) found that anatomical learning performance was predicted by the visual-spatial ability of students. Luursema, Verwey, Kommers, Geelkerken, and Vos (2006) used the same anatomical learning task as was used in the present study. They found that performance on this task was predicted by visual-spatial ability scores of the participants when the anatomy was studied using limited 2D views of the model of the anatomy. However, when participants wore 3D enabling shutter-glasses to study a fully interactive 3D model of the anatomy, the predictive value of visual-spatial ability disappeared, as it was found that performance of the low visual-spatial ability participants improved more than that of the high visual-spatial ability participants. One way to explain these results is that participants of high visual-spatial ability were using a more visual-spatial strategy that was more successful than a primarily verbal-analytical strategy, that was used by participants who were relatively low in visual-spatial ability compared to verbal-analytical ability. In the Luursema et al. (2006) study, the use of fully interactive 3D models might have caused the participants of low visual-spatial ability to switch from a primarily verbal-analytical strategy to a more visual-spatial one, thereby increasing their performance. Unfortunately, in none of the studies discussed above verbal-analytical ability or working memory span of participants was measured, and thus the relation of verbal-analytical ability and working memory span with anatomical learning performance is unknown. In the present study, therefore, both visual-spatial and verbal-analytical abilities, as well as verbal and visual spatial working memory span of participants were assessed.

The present study

The present study aimed to identify the use of verbal-analytical and visual-spatial strategies in anatomical learning. Furthermore, participants' abilities that were thought relevant to this learning were assessed, and relations between these abilities, performance, and strategy use were examined. First, participants were subjected to a number of paper-and-pencil tests of visual-spatial and verbal-analytical abilities, and of verbal and visual working memory span. Second, they were required to study two computerized 3D virtual anatomical models. After each model was studied, they performed a test that assessed the knowledge they had obtained of the anatomical models. In this test, the participants were presented with cross-sections of the model of the anatomy that they had studied. The test required participants to compare the visually presented cross-sections of the model of the anatomy with their mental representation of this model. The setup was adopted from that of Luursema et al. (2006), with the anatomical model and the task used to assess the obtained knowledge being exactly the same. Finally, participants were presented with a questionnaire concerning self reported strategy use.

In order to identify the use of a verbal-analytical or a visual-spatial strategy by the participants, a questionnaire and an interference paradigm were used. The questionnaire featured questions about the way in which participants had studied the models and had made the test that assessed their acquired knowledge. The interference paradigm was used to examine the strategy use on the test that assessed their knowledge of the anatomical models. Two interference tasks were used. These tasks were chosen with Baddeley's model of working memory (2003) in mind. His model features separate systems that are involved in the storage of verbal and visual-spatial information. To interfere with the use of a verbal-analytical strategy, an interference task was selected that disrupted verbal processing in working memory. The task that was used for this was the articulatory suppression task (e.g. Logie, 1995; Noordzij, van der Lubbe, Neggers, & Postma, 2004). In this task participants are required to repeat aloud a sequence of words. This is thought to occupy the phonological loop, which is the component of Baddeley's model of working memory that is involved in the storage of verbal information. When the articulatory suppression task is performed simultaneously with the anatomical knowledge test, the amount of resources available for the use of a verbal analytical strategy is decreased. The interference task that was chosen in order to disrupt the use of a visual-spatial strategy, was the spatial tapping task (e.g. Logie, 1995; Noordzij et al, 2004). In this task, participants have to repeatedly tap a number of spatial positions in a fixed sequence. This task is thought to place a load on the visual-spatial sketch-pad, the component of Baddeley's model of working memory involved in the storage of visual-spatial information, thereby leaving a decreased amount of resources available for other visual-spatial information.

Hypotheses and predictions

The present study featured two hypotheses. First, it was hypothesized that in anatomical learning individual differences in strategy would exist. The strategies were expected to range from a pure verbal-analytical strategy to a pure visual-spatial one. In the present study, the use of a verbal-analytical or primarily verbal-analytical strategy was expected to result in a greater performance decrease on the anatomical knowledge test, when the test was performed simultaneously with the articulatory suppression task than when performed together with the spatial tapping task. Conversely, the use of visual-spatial or primarily visual-spatial strategy was expected to result in a greater performance decrease when the anatomical learning tests were performed together with the spatial tapping task, than when performed simultaneously with the articulatory suppression task. Secondly, it was hypothesized that participants of high verbal-analytical ability would be more likely to use a more verbal-analytical strategy, while participants of high visual-spatial ability would be more likely to use a more visual-spatial strategy. Therefore, in the present study, it was expected that participants whose performance would be more affected by the articulatory suppression task than by the spatial tapping task, would be of relatively high verbal-analytical ability. Similarly, participants whose performance would be more affected by the spatial tapping task than by the articulatory suppressions task, were expected to be of relatively high visual-spatial ability.

Method

Participants

Sixty-seven right-handed students (50 females; 17 males) of the faculty of Behavioral Sciences of the University of Twente participated in return for course credit. Participants were between 18 and 27 years of age (*M* = 19.8, *SD* = 1.7), and had normal or corrected to normal vision. All were questioned about their prior knowledge of the anatomy that had to be studied in the experiment. Participants whose prior knowledge exceeded high school levels were excluded from the study. For this reason, data of 1 of the 67 participants who took part in the experiment was removed.

General procedure

The experiment required the participants to take part in three one-hour test sessions. There were multiple occasions in which each session could be attended, and the participants were free to attend the sessions in the order that suited them most. Two of these sessions, *the cognitive ability test sessions*, were group sessions. In these sessions, participants were subjected to paper-and-pencil tests that tested visual-spatial and verbal-analytical abilities and visual and verbal working memory span. The two sessions were scheduled in such a way that there were always at least 48 hours between them. In the remaining test session, *the anatomical learning session*, participants were tested individually, using a computer. In this session, participants studied two computerized 3D models, each of a different part of the human anatomy. After a model had been studied, the participants were presented with the localization task that assessed the knowledge participants had acquired of the studied anatomy. The test consisted of twenty trials which were presented in two groups of ten. For each participant, one of these groups of trials had to be performed under dual task conditions with either a verbal or a spatial interference task. Counterbalancing was used to determine if the first or second group of trials had to be performed under dual task conditions. Counterbalancing was also used to determine in which order the two models were studied, and in which order single and dual task conditions were presented. Table 1 shows the eight orders which were a result of the counterbalancing. Each participant was subjected to one of these eight orders. Finally, at the end of the anatomical learning session, participants had to fill out a questionnaire concerning self reported strategy use.

Table 1

Orders in which the two models and the verbal and spatial interference tasks were presented to the participants. Each row of the table represents one order. A cell with a dot indicates that the localization task was made under single task conditions.

	Localization task			**Localization task**	
Model 1	**Trials 1-10**	**Trials 11-20**	**Model 2**	**Trials 1-10**	**Trials 11-20**
Abdomen	.	Verbal int.	Neck	.	Spatial int.
Abdomen	.	Spatial int.	Neck	.	Verbal int.
Abdomen	Verbal int.	.	Neck	Spatial int.	.
Abdomen	Spatial int.	.	Neck	Verbal int.	.
Neck	.	Verbal int.	Abdomen	.	Spatial int.
Neck	.	Spatial int.	Abdomen	.	Verbal int.
Neck	Verbal int.	.	Abdomen	Spatial int.	.
Neck	Spatial int.	.	Abdomen	Verbal int.	.

Cognitive ability test sessions

In the cognitive ability test sessions, visual-spatial and verbal-analytical abilities of the participants, as well as their visual and verbal working memory spans were assessed. In group sessions of maximum twenty participants each, participants were subjected to paper-and-pencil tests that tested these cognitive abilities. In each of the sessions, participants made five tests in the order and at the speed the test instructor indicated. All abilities were assessed twice, once in each of the two sessions. The tests that were used, and the order in which the tests were presented, were different for each of the two sessions. For each test, the scores of the participants were divided by the maximum possible score on the test. Then, the two test scores that were obtained for each cognitive ability were averaged to form one index that indicated the participants level of ability.

Visual-spatial ability of participants was assessed by tests of Visualization (Vz) and Spatial Relations (SR). Tests of Vz measure the ability to manipulate relatively complex visual patterns, while in tests of SR the manipulation of relatively simple visual patterns is tested. A greater emphasis is placed on speed in tests of SR than in tests of VZ (Carroll, 1993). The tests of Vz that were used were the Peters' redrawn version of the Vandenberg and Kuse Mental Rotation Test (Peters et al, 1995; Vandenberg & Kuse, 1978), and the Surface Development Test from the Kit of Factor Referenced Cognitive Tests (Ekstrom, French, Harman & Dermen, 1976). SR ability of the participants was assessed by the Figures test and the Cards test (Thurstone, 1938). The verbal-analytical ability of the participants was measured by two nine-item subsets of the 36-item set II of the Raven Advanced Progressive Matrices (Raven, 1965). The subsets were selected from the items of set II that were identified by DeShon et al. (1995) as items that were predominantly solved by the use of a verbal-analytical strategy. Of the two resulting item sets, one set contained items 8, 14, 17, 19, 25, 27, 28, 31 and 34 of the original set II of the Raven Advanced Progressive Matrices, while the other item set contained items 1, 6, 13, 20, 21, 26, 29, 30 and 35. The visual working memory span tests that were used were the Shape Memory Test and the Map Memory Test. Finally, the Auditory Number Span Test and the Auditory Letter Span Test were used to test verbal working memory span. All four memory span tests were selected from the Kit of Factor Referenced Cognitive Test (Ekstrom et al., 1976). An overview of the tests that were used is presented in table 2.

Table 2

Overview of the tests that were used to assess the cognitive abilities of the participants. Participants were required to attend both sessions, although they were free to attend the sessions in the order that suited them most.

	Test session 1	**Test session 2**
Spatial Relations (SR)	Cards test *(Thurstone, 1938)*	Figures test *(Thurstone, 1938)*
Visualization (Vz)	Mental rotation test *(Peters et al, 1995; Vandenberg & Kuse, 1978)*	Surface development test *(Ekstrom et al., 1976)*
Verbal-analytical ability	Raven advanced progressive matrices Items 1, 6, 13, 20, 21, 26, 29, 30, 35 *(Raven, 1965; DeShon et al. , 1995)*	Raven advanced progressive matrices Items 8, 14, 17, 19, 25, 27, 28, 31, 34 *(Raven, 1965; DeShon et al. , 1995)*
Verbal working memory span	Auditory number span test *(Ekstrom et al., 1976)*	Auditory letter span test *(Ekstrom et al., 1976)*
Visual working memory span	Map memory test *(Ekstrom et al., 1976)*	Shape memory test *(Ekstrom et al., 1976)*

Anatomical learning session

In the anatomical learning session, participants were tested individually. They were seated at a desk, facing a computer screen. The desk was placed in a cubicle that was shut off from outside disturbances. During the whole session, the researcher was present. The session started with the researcher explaining the procedure in general lines. Next, the participants received verbal instructions from the experimenter about the interference tasks, after which they practiced the tasks. For the articulatory suppression task, participants were told to count aloud from one to four repeatedly. The speed at which they had to count was indicated by a beep that sounded at a rate of three times a second. This task was practiced until the participants were able to count at the right speed for 30 seconds without interruption, and felt comfortable doing so. For the spatial tapping task, participants were instructed to use a pen to touch, in a clockwise direction, four patches that were arranged in a square. The patches were made of square sponges of 70x70 mm. The patches were placed in four holes of a corresponding size in a wooden board, with a spacing of 25 mm between the holes. The wooden board with the sponges was placed over an electronic drawing tablet. Touches on the sponge surfaces with the pen were registered by a computer that was connected to the drawing tablet via an USB connection. The patches were made of sponges to provide the participants with both tactile and auditory feedback, as the difference between touching the hard wooden board or the soft sponges with the pen was clearly distinct by both touch and sound. This was necessary as the wooden board with the sponges was occluded from the participants´ vision by a sheet of cardboard. Participants were instructed to touch the four sponge surfaces in a clockwise direction with the pen at rate of three touches per second. In the same manner as with the articulatory suppression task, the correct rate was indicated by a beep. Participants practiced until they were able to touch the correct patch 90% of the time over a 30 second period.

After the interference tasks were practiced, no more verbal instructions were given by the experimenter. The participants were told to follow the instructions on the computer screen. However, the participants were informed they were free to ask the experimenter questions in case the on-screen instructions were not clear to them. First, the localization task that would follow the presentation of a model was explained. Then a sample trial of the test was presented. Participants were instructed to pay attention to what was required of them in this task, so that they could prepare themselves for this task during the study phase. Before the model was presented, the participants were instructed to put on the 3D enabling shutter-glasses. After they had put on the glasses and indicated they were ready, the model of the anatomy was presented. This could be either a model of the anatomy of the human abdomen, or a model of the anatomy of the human neck. All participants studied both models. The order in which the models were presented was counterbalanced between participants. The model rotated around its vertical axes at a constant pace. Next to the model, on the left side of the screen, three pictures featuring a frontal view of the anatomy were shown together with the names of the different parts of the anatomy (figure 1). The participants were allowed to study the model for exactly three minutes, before it disappeared automatically.

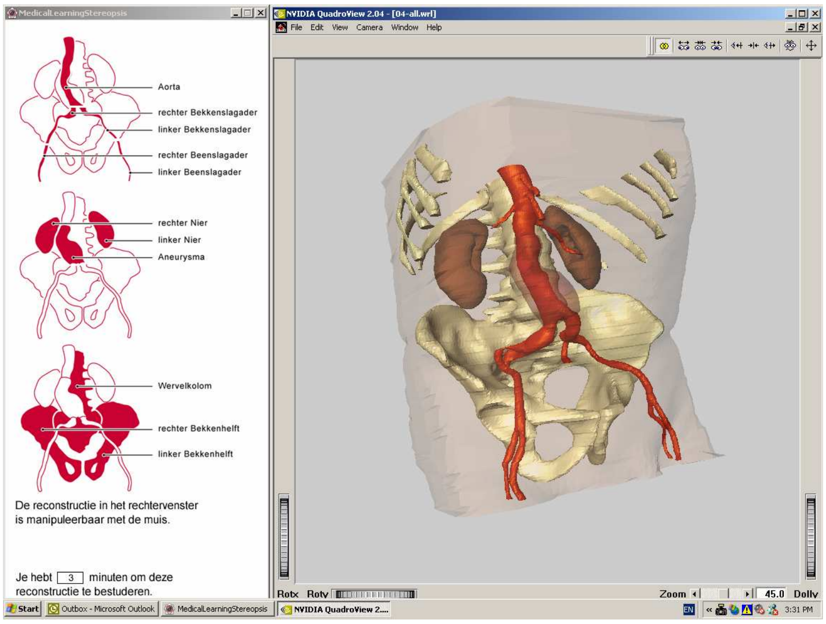

Figure 1. Screenshot from the study phase of the experiment in which participants studied a model of the human abdomen. Participants wore 3D enabling shutter glasses to perceive depth.

Localization task

After they had studied a model, the participants were subjected to the localization task. The presentation of the task that followed the first model was preceded by a repeat of the instructions that had already been presented with the sample trial before the first model was studied. When the participants were subjected to the localization task after studying the second model, only a short summary of the instructions was given. However, participants were notified that a printed version of the full instructions was available on the desk beside the computer screen. They were free to read the full instructions in case they felt they needed more information than was provided by the summarized on-screen version. The participants were then presented with a number of practice trials. The number of practice trials depended on the model that was just studied; three trials were presented in case the anatomy of the abdomen was studied, four in case of the anatomy of the neck. The number of trials differed due to the limited number of uniquely available trials for each model. The localization task featured a total of twenty trials, which were presented in two groups of ten each. The order in which the trials appeared in each group was randomized.

For each trial, the left side of the screen showed a frontal-view screenshot of the model that was studied. Over this screenshot, a number of horizontal lines was drawn. On the right side of the screen, a similar picture of an anatomical CT cross-section was shown. The task of the participants was to indicate the level from which the cross-section was taken. A test trial started when participants pressed the ‘5’ key on the numeric keypad of the keyboard. Participants were instructed not to release the key until they thought they had identified the correct height in the frontal-view screenshot of the model. When the key was released, the cross-section disappeared, leaving only the frontal-view screenshot on screen. If after thirty seconds the ‘5’ key had not been released, the cross-section disappeared any way. After the picture of the cross-section had disappeared, the frontal-view screenshot of the model remained. The participants then had to use the mouse to click on the line drawn over the screenshot that they thought corresponded with the correct level. The reaction time was defined as the time that the ‘5’ key was pressed. Errors were defined as clicking on an incorrect line over the frontal-view screenshot, or failing to click on a line at all. After each trial, a message was shown indicating whether the right line was clicked or not. Trials of which participants verbally informed the experimenter that they had accidentally released the ‘5’ key or accidentally clicked the wrong answer, were removed from the analyses. An example of a trial of the localization task is shown in figure 2.

Before the participants performed each localization task, they were presented with a task that also assessed their knowledge of the anatomical model. This task consisted of twenty trials that featured similar anatomical cross-sections as were used in the localization task. These twenty trials were also divided into two groups of ten. Similar to the localization task, one of these two groups of trials also had to be made under dual task conditions, with either the verbal or spatial interference task. The results of this task showed an interaction effect between task condition (single and dual) and the order in which these two task conditions were presented. Participants were found to always perform better on the second group of trials, regardless whether this group was made under single or dual task condition. This made it impossible to reliably analyze the results. Therefore this task will not be discussed further in this paper.

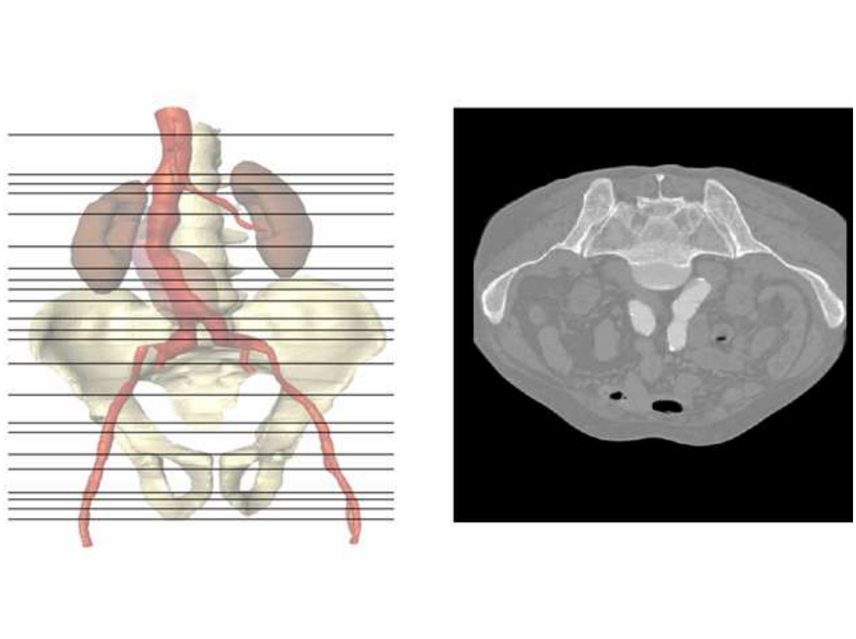

Figure 2. Screenshot of an item of the localization task that followed the study phase in which participants had studied a model of the human abdomen. Participants were required to select the line over the front-view on the left that they thought corresponded with the level at which the cross-section on the right was taken.

Interference tasks

Both localization tasks featured twenty items, which were presented in two groups of ten trials each. One of these two groups of trials had to be made while the participants simultaneously performed either the articulatory suppression task, or the spatial tapping task. Before this group of trials was presented, participants first received instructions about how to perform the two tasks simultaneously. They were explicitly instructed that it was of utmost importance to perform as best as they could on the interference task, even if this meant that performance on the anatomical learning tasks would suffer. Then, the practice trials that had been presented before were repeated, so participants could practice the simultaneous performance of the two tasks. All participants had to perform the localization task once with each of the inference tasks. The localization task that followed the presentation of the first model was combined with one interference task, while the localization task that followed the second model was combined with the other interference task. The order in which this happened was counterbalanced.

In the *articulatory suppression task*, the participants were required to count aloud from one to four repeatedly. A beep sounded to indicate the correct speed of counting. This beep started just before participants pressed the ‘5’ key to start the first trial, and disappeared only after all ten trials were completed. Participants were instructed to start counting and have counted at least once from one to four, before they pressed the ‘5’ key, and not to stop counting until they had released the ‘5’ key. Thus, between trials, no counting was required. The researcher was present during the whole experiment and noted down the trials during which participants stopped counting, skipped a digit, or clearly did not count at the indicated speed. These trials were later removed from the data. In the *spatial tapping task*, the same procedure was followed. Again, the beep indicating the correct speed of tapping sounded from just before the first trial until after the last trial. Participants were instructed to start tapping before pressing the ‘5’ key to start the next trial, and not to stop until they had released the key again. They were required to tap at least four times before pressing the ‘5’ key. Participants were explicitly instructed to keep looking at the computer screen and not to look around the piece of card board that was used to occlude the tapping board from the participants’ vision. Trials during which participants failed to do so were excluded from further analysis. Every tap on one of the four sponge surfaces was registered a drawing tablet that was placed under the board with the sponges. The drawing tablet was connected to a computer that verified if the correct sponge surface was touched at the corrected moment. Trials during which participants failed to tap the correct sponge surface for 80 percent or less of the time were removed from the data.

Questionnaire

Finally, at the end of the anatomical testing session, participants were required to fill out a questionnaire. The questionnaire featured fourteen statements which concerned both the study phase and the localization task. Statements were included that addressed how the models were studied, how familiar participants were with the models, the use of visual-spatial and verbal-analytical strategies, and the effects of the interference tasks on strategies. All statements were each presented twice, once positively framed, and once negatively. Thus, the questionnaire featured a total of 28 statements. For each statement, participants indicated how much they agreed with the statement on a scale from 1 to 5. On this scale, full disagreement with a statement was indicated by 1, while 5 indicated full agreement. The questionnaire was an expanded version of the questionnaire used by Kirchhoff and Buckner (2006). The questionnaire is included in appendix A.

Apparatus

The anatomical learning session was run on a Pentium IV class PC with Windows XP as operating system. The computer featured a PNY-Quadro 4 580XGL videocard and a 19” Ilyama Vision Master Pro CRT-monitor. The setup further included Stereographic’s CrystalEyes CE-3 active shutter-glasses, and an E-2 emitter and stereoEnabler. Together, this setup was able to produce a monitor refresh rate of 140 Hz. This resulted in an effective refresh rate of 70 Hz with the use of the left and right alternating shutter glasses, which enabled the anatomical models to be presented without noticeable flicker. The 3D anatomical models were constructed from CT-Data of actual patients. The model of the abdomen was also used in the study of Luursema et al. (2006). The Surfdriver software package was used to automatically generate 3D DXF models, by tracing the relevant anatomy in every slice. These models were post-processed in 3D Max and Cosmoworlds to create VRML models for use in the experiment. The Nvidia QuadroView 2.04 application was used to present the models to the participants. The E-Prime 1.1 experimental software package was used to create the part of the experiment that featured the anatomical learning tests, including instructions, sample items and log files. The interference tasks were also created with the E-Prime software and were run on a second computer which was controlled by the experimenter. This second computer was also a Pentium IV class PC. The wooden board with the four sponge patches used for the spatial tapping task was placed over a Wacom Intuos2 A4 Regular drawing tablet.

Data analysis

Before the results were analysed, the scores on the two tests that were used to assess each cognitive ability were converted to percentages of the maximum possible score on the tests. These two percentages were then averaged in order to form one index for each participant’s cognitive ability. Kolmogorov-Smirnov tests revealed that the distributions of the five resulting cognitive ability indexes did not differ significantly from a normal distribution.

For each participant, trials of the localization task during which they failed to perform the interference tasks correctly were removed. For the verbal interference task this meant that on average 1.1% of the total number of trials was removed, while for the spatial interference task an average of 18% of all trials was removed. Data of participants who failed to answer at least one trial of the localization task correctly under single task conditions were also removed from the analyses of that particular interference task. This meant that in case of the verbal interference task, data from the localization task of 7 participants, which was 11% of the total number of participants, was omitted from further analyses. In case of the spatial interference task, data of 9 participants, 14% of the total number, was removed. To be able to compare the effects of the two interference tasks on performance of the localization task, relative changes between single and dual task performance on the localization task were calculated by subtracting accuracy under single task conditions from accuracy under dual task conditions and dividing the result by accuracy under single task conditions. Furthermore, relative changes in reaction time were calculated by subtracting reaction time under dual task conditions from reaction time under single task conditions, and dividing the result by reaction time under single task conditions. In this way a decrease in performance was always indicated by a negative percentage, and an increase in performance by a positive percentage, for both accuracy and reaction time. Kolmogorov-Smirnov tests revealed that none of the distributions of the variables representing these relative differences in performance differed significantly from a normal distribution. The resulting data set was then subjected to the analyses that are described in the results section below.

Results

Cognitive ability test sessions

The descriptive statistics for the five indexes, together with the correlations between the two tests that were used to assess each ability, are shown in table 3. Data from one participant for one of the auditory working memory tests was removed due to a misunderstanding of the instructions.

Table 3
Descriptive statistics for the five indexes of cognitive ability and correlations between the two tests that were used to measure each ability

	N	Min	Max	M	SD	r
Spatial Relations (SR)	66	.14	.96	.59	.19	.603 **
Visualization (Vz)	66	.19	.98	.57	.18	.423 **
Visual WM span	66	.34	.98	.71	.16	.419 **
Auditory WM span	65	.08	.50	.26	.08	.331 *
Raven Matrices	66	.17	.94	.59	.17	.327 **

*** significant at the p<.01 level, two-tailed*
** significant at the p<.05 level, two-tailed*

Effects of interference tasks

Figure 3 shows means and standard deviations for both accuracy and reaction time on the localization task under single and dual task conditions with either verbal or spatial interference.

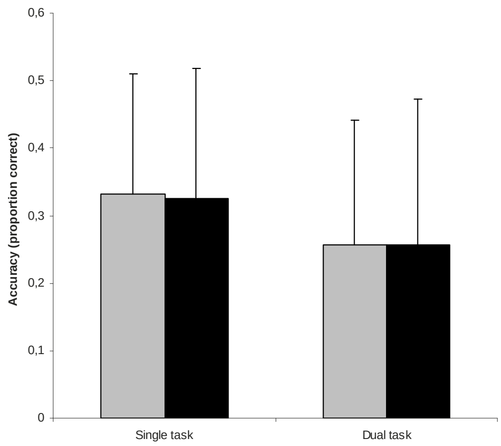

Figure 3a: *Means and standard deviations for accuracy on the localization task under single and dual task conditions with verbal and spatial interference*

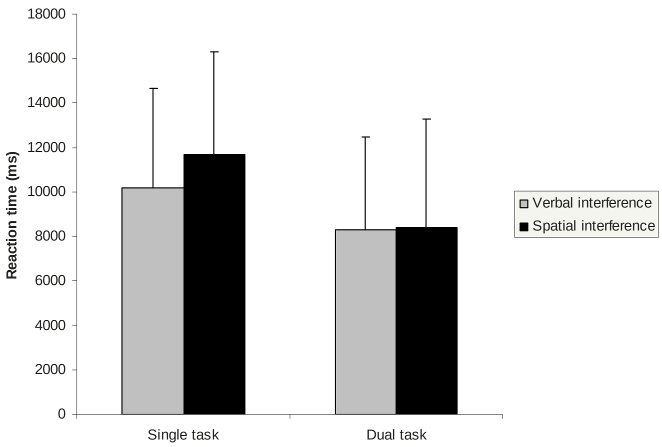

Figure 3b: *Means and standard deviations for reaction time on the localization task under single and dual task conditions with verbal and spatial interference*

First, it was examined if there were differences between the two interference tasks in their effect on accuracy of the localization task. To that extent, a repeated measures ANOVA was performed with interference task (verbal or spatial) as within-subjects variable and the relative difference in accuracy between single and dual task conditions as dependent variable. No significant difference was found. Neither was a significant difference found when another repeated measures ANOVA was performed with reaction time as dependent variable.

Next, the effects of the two inference tasks were examined in more detail. For the verbal interference task, repeated-measures ANOVAs were performed with task condition (single or dual) as within-subjects variable and accuracy or reaction time as dependent variable. The ANOVA of accuracy on the localization task showed a significant effect of task condition, $F(1, 58) = 11.56$, $p < .01$. Thus, participants performed with lower accuracy on the localization task when it was presented under dual task conditions. The analysis of reaction time also revealed a significant effect of the interference task, $F(1, 49) = 10.00$, $p < .01$. This means that participants on average reacted faster under dual task conditions than under single task conditions. No significant correlation was found between the relative differences in accuracy and reaction time between single and dual task conditions.

For the spatial interference task, the repeated-measures ANOVA of accuracy on the localization task revealed a significant effect of task condition, $F(1, 58) = 10.654$, $p < .01$. Thus, participants had lower accuracy on the localization task when it was performed together with the spatial interference task, than when it was performed under single task conditions. The ANOVA of reaction time also showed a significant effect of task condition, $F(1, 45) = 26.92$, $p < .001$. These results mean that the spatial interference task also caused participants to perform the localization task both faster and less accurate under dual task conditions. Again, no significant correlation was found between the relative differences in accuracy and reaction time between single and dual task conditions.

Cognitive abilities and effects of interference

The relation between cognitive abilities and the effects of the interference tasks were examined next. To this end, two multiple regression analyses were performed, in which the five cognitive ability indexes of the participants were entered stepwise as independent variables. Relative differences in accuracy and reaction time on the localization task between single and dual task conditions were entered as the dependent variable. The analysis with relative difference in accuracy, between single and dual task conditions with the verbal interference task, as the dependent variable showed a significant model with Visualization as the only predictor, $F(1, 56) = 4.20$, $p < .05$, $r^2 = .07$. The analysis with relative difference in reaction time as the dependent variable yielded a significant model with auditory working memory span as a sole predictor, $F(1, 47) = 7.23$, $p < .01$, $r^2 = .13$. Thus, the reduction in accuracy on the localization task between single and dual task conditions was best predicted by the Visualization score of a participant. The reduction in reaction time, however, was best predicted by the auditory working memory span score of participants. The last relation was negative, meaning that higher auditory working memory span scores were associated with decreased performance, as was shown by increased reaction times. Table 4 shows the results from the multiple regression analyses.

To examine the relations of cognitive abilities with the effects of spatial interference, two further multiple regression analyses were performed. The analysis with the relative difference in accuracy on the localization task as the dependent variable yielded no significant model. The analysis with relative difference in reaction time as dependent variable also did not reveal a significant model. Thus, no predictors were found for the relative differences in accuracy and reaction time between single and dual task conditions with spatial interference.

Table 4

Significant variables for the multiple regression analyses with the five cognitive ability scores as independent variables and relative changes in accuracy and reaction time between single and dual task (articulatory suppression) conditions respectively as dependent variable

		B	**Std. Error**	**t**	**p**
Accuracy					
	Constant	-.709	.269	-2.640	< .05
	Visualization	.906	.442	2.049	< .05
Reaction time					
	Constant	.590	.178	3.311	< .05
	Auditory working memory span	-1.750	.651	-2.689	< .01

To further examine the relations between cognitive abilities and the effects of the interference tasks, the relations of cognitive abilities with performance under single task conditions, and with performance under dual task conditions were considered. To this end, further multiple regression analyses were performed, in which the five cognitive ability indexes of the participants again were entered stepwise as independent variables. For verbal interference, the analysis with accuracy under single task conditions as dependent variable resulted in a significant model, $F(1, 56) = 13.312$, $p < .001$, $r^2 = .192$, with Visualization as the only significant predictor variable. When an analysis was performed with accuracy under dual task conditions as the dependent variable, again a significant model with Visualization as the only significant predictor emerged, $F(1, 56) = 18.138$, $p < .001$, $r^2 = .245$. Thus, for accuracy on the localization task under both single and dual task conditions, Visualization was the only predictor. Table 5 shows the results from the multiple regression analyses.

Table 5

Significant variables for the multiple regression analyses with the five cognitive ability scores as independent variables and accuracy under single and dual task (articulatory suppression) conditions respectively as dependent variable

		B	Std. Error	t	p
Single task conditions					
	Constant	.065	.076	.851	.398
	Visualization	.458	.125	3.649	< .001
Dual task conditions					
	Constant	-.051	.076	-.674	.503
	Visualization	.533	.125	4.259	< .001

For spatial interference, the analysis with accuracy on the localization task under single task conditions as the dependent variable resulted in a significant model with Visualization as the only significant predictor, $F(1, 57) = 8.29$, $p < .05$, $r^2 = .13$. With accuracy under dual task conditions as the dependent variable, the analysis yielded a significant model with verbal-analytical ability, as measured by the Raven matrices test, as the sole predictor, $F(1, 57) = 4.61$, $p < .05$, $r^2 = .08$. Thus, under single task conditions the Visualization score was the best predictor of accuracy on the localization task, while under dual task conditions this was the Raven matrices score. This difference in predictors between single and dual task conditions is interesting as no significant predictor was found for the relative difference in accuracy between single and dual task conditions. Table 6 shows the results from these multiple regression analyses.

Table 6

Significant variables for the multiple regression analyses with the five cognitive ability scores as independent variables and accuracy under single and dual task (spatial tapping) conditions respectively as dependent variable

		B	Std. Error	t	p
Single task conditions					
	Constant	.090	.085	1.052	.297
	Visualization	.403	.140	2.879	< .01
Dual task conditions					
	Constant	.040	.105	.378	.707
	Raven matrices	.363	.169	2.146	< .05

Questionnaire

A one-way ANOVA was used to examine if there was a difference in familiarity of participants with the anatomy of the abdomen (Appendix A, question 6) and the neck (question 7). The analysis revealed that participants were more familiar with the anatomy of the abdomen (M = 4.19, SD = .94) than they were with that of the neck (M = 3.80, SD = 1.11), $F(1,64) = 4.846$, $p < .05$. Then, the relations between answers on the questionnaire and the effects of the interference tasks were examined. To that end, correlations were computed between the answers participants gave to the questionnaire and relative differences in performance between single and dual task conditions. No significant correlations were found between the answers and either relative differences in accuracy or reaction time for both verbal and spatial interference. Next, the relation between performance on the localization task and the answers participants gave were examined by computing correlations between the two. Accuracy under dual task conditions with the articulatory suppression task was found to be significantly correlated with the reported use of mental imagery during the study phase (question 5). Accuracy under dual task conditions with the spatial tapping task correlated significantly with both reported use of mental imagery (question 10) and internal speech (question 11) on the localization task. These were the only significant correlations that were found and are shown in table 7.

Table 7
Significant correlations between the answers on the questionnaire and accuracy under single and dual task conditions with verbal and spatial interference

	Verbal interference		**Spatial interference**	
	Single task	**Dual task**	**Single task**	**Dual task**
Study phase				
Used mental imagery		.357 **		
Localization task				
Used mental imagery				.354 **
Used internal speech				.275 *

*** significant at the p<.01 level, two-tailed*
** significant at the p<.05 level, two-tailed*

Discussion

In the present study the use of verbal-analytical and visual-spatial strategies in anatomical learning was examined. This was done in a task that assessed visual-spatial knowledge that participants had acquired of anatomical models that they studied before. The relations of cognitive abilities and working memory span of the participants with strategy use were also examined. A questionnaire and two interference tasks were used to identify strategies. Articulatory suppression was used to interfere with the use of a verbal-analytical strategy, while spatial tapping was used to interfere with the use of a visual-spatial strategy.

The results showed that under dual task conditions participants both made more errors and were faster than under single task conditions. This was true for both interference tasks. One explanation for this could be a speed-accuracy trade-off. The participants might have experienced the simultaneous performance of an interference task as difficult or annoying, which caused the participants to spend less time solving the trials of the localization under dual task conditions, and as a result had a detrimental effect on accuracy. The extent of the decrease in reaction time would then be expected to be related to the extent of decrease in accuracy, as less time spend on the localization task would mean lower accuracy. However, for neither of the interference tasks such a relation was found to be significant. A strong speed-accuracy trade-off therefore seems unlikely. Nevertheless, the finding of a decrease in both accuracy and reaction time under dual task conditions, combined with the absence of a relation between the two, is interesting. It means that on average both accuracy and reaction decreased, but that the amount with which each decreased was independent of each other. Thus, there were individual differences in how participants were affected by the two interference tasks.

To further examine the effects of the interference tasks, their relations with cognitive abilities were considered. For verbal interference, Visualization was found to be the predictor of the extent that accuracy decreased under dual task conditions. Participants of relatively high Visualization ability were found to suffer the least from verbal interference. This suggests that participants of relatively high Visualization were using a strategy that relied less on verbal resources of working memory than relatively low Visualization ability participants. Thus, as hypothesized, participants of relatively high visual-spatial abilities were expected to be using a more visual-spatial strategy. When reaction time was considered, the size of participants' auditory working memory span was found to predict the relative decrease in reaction time on the localization task from single to dual task conditions. Higher auditory working memory span sizes were associated with greater decreases in reaction time. Thus, participants with relatively large auditory working memory spans gained the most from verbal interference when reaction times were concerned. This result seems to be in conflict with the hypothesis that participants of relatively large verbal-analytical ability were expected to suffer the most from verbal interference. However, when considering that verbal-analytical strategies have reliably been found to be slower than visual-spatial strategies (Cooper, 1982; Bethell-Fox and Shepard, 1988), these participants may have switched to a less time consuming strategy of a more visual-spatial nature. This positive result of verbal interference was not anticipated, but has been found before. Philips, Wynn, Gilhooly, Della Sala and Logie (1999) studied the Tower of London task, and found that the articulatory suppression task caused faster performance of this task. They gave a similar explanation as they argued that articulatory suppression prevented the participants from using the phonological loop for verbal rehearsal on the task, causing the participants to switch to a more optimal strategy that involved the visual-spatial sketch-pad.

For spatial interference, no predictors were found when the relations of the cognitive abilities and working memory span with the relative differences in performance between single and dual task conditions were examined. This might have been caused by the removal of a substantial part of the data due to participants failing to perform the spatial tapping task correctly. As a result the power of the analyses decreased. However, the finding that participants were having difficulties with performing the spatial tapping task up to the set criteria is interesting. Especially considering that the spatial tapping task featured the same specifications as was used in Noordzij et al. (2004), who did not report high error rates. One explanation for this difference could be that the task they used the spatial tapping task to interfere with, a sentence-picture verification task, was of relative little complexity compared to the localization task in the presented study. Therefore, in the present study, despite being explicitly instructed to give priority to the interference tasks, participants might have failed to do so and let the localization task impair their spatial tapping performance. However, this would mean that the localization task always required an amount of visual-spatial resources, regardless of which strategy was used. This is plausible considering the finding that Visualization emerged as the only predictor of accuracy under single task conditions, accuracy under dual task conditions with verbal interference, and accuracy differences between single and dual task conditions with verbal interference. Furthermore, Visualization has been found to be related to anatomical learning performance before (Luursema et al, 2006; Garg et al., 2001; Wanzel et al., 2002).

The relations between the effects of spatial interference and cognitive abilities were further examined by considering the relations of performance under single task conditions and performance under dual task conditions with cognitive abilities. Under single task conditions Visualization was the only significant predictor of accuracy, while under dual task conditions verbal analytical ability, as measured by the Raven matrices test, was the only significant predictor of accuracy. This is in line with the expectation that the spatial tapping task would interfere with visual-spatial processing in working memory, causing visual-spatial ability to lose predictive value to verbal-analytical ability. The suggestion that visual-spatial working memory resources were always required by the strategy participants were using, means that the participants under single task conditions were either using a fully visual-spatial strategy, or an intermediate strategy that required both visual-spatial and verbal-analytical working memory resources. The finding that both interference tasks on average had a similar effect, decreased accuracy and lower reaction times, and the finding that no differences in effect between the two interference tasks were found, suggest the latter. The finding of Visualization as the only significant predictor under single task conditions suggests that the visual-spatial working memory resources were most important. The results further suggest that the amount in which participants relied on verbal-analytical and visual-spatial working memory resources was mediated by their cognitive abilities. The suggestion that participants did not use a purely verbal-analytical or visual-spatial strategy, is plausible considering the relatively high complexity of human anatomy, as was studied in the present experiment, when compared the material used in the studies that made the distinction between pure verbal-analytical and visual-spatial strategies (Cooper, 1982; Bethell-Fox and Shepard, 1988). Furthermore, it is also in line with Glück and Fitting (2003) who argued that high levels of stimulus complexity are related to the use of intermediate strategies.

Thus, the results of the present study suggest that under single task conditions individual differences in strategies existed. However, these strategies were neither pure verbal-analytical, nor pure visual-spatial as the results indicate that the strategy that was used relied on both verbal-analytical and visual-spatial working memory resources. Although both resources were required, the latter was thought to be the most important of the two. The extent to which participants relied on both resources was suggested to be mediated by their cognitive abilities.

Questionnaire

Very few relations between answers on the questionnaire and performance on the localization task were found. However, the results that were found were in line with what one would expect considering the general trend of the behavioural data. Higher reported use of mental imagery during the study phase was related to higher accuracy under dual task conditions with verbal interference. This was expected as participants who were using a more visual-spatial strategy should suffer less from verbal interference. It also emphasizes the importance of Visualization as a predictor of accuracy. Both higher reported use of mental imagery and internal speech were related to higher accuracy under dual task conditions with spatial interference. This confirms the suggestion that both verbal-analytical and visual-spatial resources play a role in the strategy that participants used. The finding that under dual task conditions with spatial interference a relationship existed between accuracy and reported use of mental imagery, further emphasises the importance of visual-spatial abilities. Finally, the finding that only a very few relations existed between answers on the questionnaire and performance on the localization task suggests that participants were not very aware of the strategy they used.

Limitations and recommendations

The present study was limited in a number of ways. An important limitation was that a substantial part of the data was omitted from the analyses, as performance of the participants did not reach the set criteria. On the localization task under single task conditions, a number of participants failed to answer at least one trial correct. This suggests that the localization task might have been too difficult for the current group of participants. However, the number of trials of the localization task was small, which gave the participants little room for error. The number of trials was only half of that when the localization task was used in Luursema et al. (2006), as in the current study the trials were divided over two groups, one to be performed under single task conditions, and one under dual task conditions.

The number of trials under dual task conditions was further reduced by the removal of trials during which participants failed to perform the interference tasks to the set criteria. The number of trials of the localization task that was removed due to participants failing to perform the spatial tapping task correctly was also substantial. As was discussed above, this might have been the result of the localization task always requiring an amount of visual-spatial resources. Despite being explicitly instructed that the interference tasks had to be given priority, participants might have failed to do so and let the localization task impair their spatial tapping performance. In future studies it is therefore recommended to better control priority participants give to the interference tasks. It would also be recommended to vary the difficulty of the interference tasks. This could be used to examine whether the present results could be reproduced with a less difficult spatial tapping task, thus when all participants would be able to perform the spatial tapping task at the level of the set criteria. It would also be interesting to vary the difficulty of the interference tasks to examine when the participants' performance starts to suffer. If with an interference task of low difficulty, individuals could be influenced to adopt to a more successful strategy, this could be used for training purposes.

Furthermore, as the interference task might have caused some participants to change their strategy, this may also have had an effect on strategy use under single task conditions, when dual task conditions preceded single task conditions. Future studies might control for this by only presenting dual task conditions after single task conditions, and providing a control group to examine the effects of the dual task conditions. Finally, another recommendation for future studies would be to use neuroimaging techniques to examine which brain areas are involved in the use of these strategies, which could provide further evidence for the use these different strategies.

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Appendix A

Translated version of the questionnaire that was presented in Dutch at the end of the anatomical learning session. Each statement was presented twice, once positively framed and once negatively. Responses were given on a 5 point scale ranging from totally disagree to totally agree.

Study phase

1. I paid attention to the colours used in the models
2. I paid attention to the shapes of the separate parts of the models
3. I paid attention to the positioning of the separate parts of the models
4. I spoke to myself while studying the models
5. I used mental imagery when studying the models
6. The model of the abdomen was new to me
7. The model of the neck was new to me
8. I found the model of the neck harder to memorize than that of the abdomen
9. I used different ways to study the two models

Localization test

10. I used mental imagery when solving the trials
11. I spoke to myself when solving the trials
12. I used a different way of solving the trials during verbal interference
13. I used a different way of solving the trials during spatial interference
14. I used the same way of solving the trials all the time