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Research Article

The Use of Spatial Cognitive Abilities in Geographical Information Systems: The Map Overlay Operation

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Abstract

Spatial cognitive abilities play an important role in the use of GIS, although they have yet to be examined in a controlled experimental setting This study aimed to develop an experimental design which measures spatial cognitive abilities in the use of GIS, specifically the map overlay operation. Subjects ($n = 134$) received three map overlay tests in which they were given two of the following input map layers, logical operator(s), or output map layer(s). Subjects were required to select the correct logical operator for Test 1, to select the correct output map layer for Test 2, and to select the correct input map layers for Test 3. Each test contained a total of 16 questions, based on a 4 ('and', 'or', 'xor', 'not' operators) × 2 (one or two polygons per map layer) × 2 (three or five polygon edges) factorial design. Results indicated a significant main effect of logical operators and number of polygons on performance; however, there was no effect of the number of polygon edges on performance Significant two-way interactions revealed an effect of the number of polygon edges and the number of polygons using various logical operators on performance. In addition, performance was not significantly different between males and females or between GIS users and non-users. Overall, results show that map overlays in which a visual correspondence can be made between the same polygons in the input and output map layers are cognitively less demanding than map overlays in which the shape of the polygons have been radically transformed between the input and output map layers. This study helps further develop our understanding of the spatial cognitive abilities which are required in the use of GIS, and whether certain sub-populations differ in these cognitive abilities. These results may contribute to more effective and efficient GIS teaching and interface design by taking into account individual spatial cognitive abilities.

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1 Introduction

The use and sophistication of GIS have increased dramatically during the 1990s. Along with this dramatic change has emerged an awareness of cognitive factors involved in the use of GIS (Turk 1990, Mark and Frank 1991; Medyckyj-Scott and Blades 1992, Medyckyj-Scott and Hearnshaw 1993, Mark and Egenhofer 1994, Montello and Freundschuh 1995, Nyerges et al 1995) Cognitive factors in GIS are particularly important since a GIS involves a more complicated set of operations and decision-making processes relative to other information systems (Nyerges 1993). In a GIS domain, research on cognitive factors generally focuses on how individuals are able to mentally encode, process, store, and retrieve geographic information and why certain individuals are better or worse in these activities. The primary goal of this research was to design a GIS which is consistent with how the GIS-user thinks about geographic or spatial information, so that essentially the software and hardware become invisible to the user (Mark and Freundschuh 1995) To accomplish this, a GIS must take into account cognitive factors such as the natural use of spatial language, cross-cultural differences (Gould 1991), individuals with varying levels of skill (Nyerges 1995), individuals from a wide variety of disciplines (Mark 1993), and a wide range of individual differences between users, such as spatial cognitive abilities (Mark 1993).

This study examined spatial cognitive abilities in the use of GIS, specifically in relation to the map overlay operation Spatial cognitive abilities allow the GIS-user to store into memory geographic information in the form of spatial objects or patterns of spatial objects and to perform mental operations on those spatial objects. These abilities are important for fundamental tasks such as remembering what a specific map looks like, determining if a spatial pattern exists among different spatial objects on a map, determining the appropriate sequence of GIS operations or commands to produce a desired outcome, or trying to visualize 3-D topography from an alternative perspective In the context of the map overlay operation, spatial cognitive abilities allow the GIS-user to perform a variety of tasks, such as determining the correct overlay operator, visually verifying the resultant map product, and determining how new spatial objects are created with different logical operators

This study addressed two fundamental questions. First, how do different aspects of the map overlay operation vary in their spatial cognitive requirements? The answer to this question will reveal which aspects of the map overlay operation are cognitively more demanding than others. Second, do specific subpopulations differ in their spatial cognitive abilities required in the use of the map overlay operation? Is there any difference in the way GIS-users and non-users or males and females mentally manipulate spatial objects and visualize complex spatial patterns? Taken together, the answers to both of these questions will offer a clearer picture of the cognitive processes involved in the map overlay operation, and the use of GIS in general.

2 Cognition and GIS

Past research on cognitive aspects of GIS has focused on the relationship between how geographic information is internally and externally represented by the GIS, how users perceive and conceive of this information, and how users perceive and conceive of features and relationships in the world. Cognitive research in geographic information may address a host of questions, such as How do individuals mentally represent geographic information? How do individual differences play a role in understanding geographic information? How does the medium of presentation (numeric, maps, animation, simulations, navigation) affect the mental representation of geographic information? How do people use natural language to describe complex geographic situations? What concepts do people use to reason about geographic space?

Nyerges (1995) provides a useful theoretical framework for examining the role of cognition in the use of GIS He suggests that GIS-user knowledge is based on the integration of two knowledge domains: problem-domain knowledge and tool-domain knowledge Problem-domain knowledge involves everyday knowledge of the real world (conventional spatial knowledge) and professional spatial knowledge (a set of concepts based on abstract space, specific to a particular discipline). Tool-domain knowledge involves problem-solving abilities within the context of a particular GIS Together, these two types of knowledge are developed through a series of mental models at three different levels declarative, procedural, and configurational Declarative knowledge is knowing a fact, such as knowing a particular function exists in a GIS (e.g map overlay) Procedural knowledge is knowing how to perform a particular function, such as the steps needed to perform a map overlay Configurational knowledge is knowing the relations between distinct objects or ideas, such as how different GIS functions interact Problems that beg examination include determining how objects from a multitude of map overlays interact and developing a cognitive processing model for GIS Other problems yet to be solved concern the ways that users with varying levels of expert or novice knowledge in the problem-domain and tool-domain differ in their use of GIS This will be achieved by clarifying the role of spatial cognitive abilities in the development from novice to expert in either knowledge domain, and specifying the way that spatial cognitive abilities influence the development of mental models at various knowledge levels

Despite a plethora of problems, there have been few attempts to examine spatial cognitive abilities in the use of GIS, even though there have been suggestions in recent literature that they may play an important role in the use of GIS. Nyerges (1993) suggested that the use of GIS, to some extent, is governed by an individual's psychological make-up, which includes spatial ability, spatial knowledge retention, problem-solving ability, and the degree of cognitive control of mental strategies Mark (1993) suggested that individual variability in spatial tasks should be taken into account in the interface design of a GIS Turk (1993) asserted that human computer interaction (HCI) factors in GIS must take into account human factors which are common to all GIS-users, human factors which vary between users, and factors which vary within the user By examining these three facets of individual differences, a theoretical model relating GIS-use and individual differences may be applied to more efficient design of user interfaces and optimization of HCI for GIS. This study provides a means by which cognitive aspects of GIS may be examined in a controlled experimental setting.

3 Spatial Cognitive Abilities and GIS

Spatial abilities have been considered a unique aspect of human intelligence since the 1930s (see McGee 1979 for a review). Spatial abilities may be useful for successful performance in a wide variety of professions such as architecture, graphic design, medicine, engineering, art, chemistry, geography, mathematics, planning, and physics Individuals in all of these professions share the need to be able to visualize spatial stimuli and configurations from different visual perspectives, perform mental operations on those stimuli such as mental rotation, and recognize spatial patterns among a complex visual array In general, spatial abilities involve the retention, manipulation, and recognition of spatial stimuli. Spatial abilities are commonly subdivided into two distinct factors· spatial orientation and spatial visualization (Lohman 1979, McGee 1979). A third factor, spatial relations, has also been suggested as a unique aspect of spatial abilities (Eliot and McFarlane-Smith 1983, Gilmartin and Patton 1984, Self et al 1992, Golledge et al 1995).

Spatial orientation is the ability to imagine how a visual stimulus or configuration looks from a different perspective Spatial orientation requires individuals to re-orient themselves relative to a visual array (Pellegrino and Kail 1982) For example, spatial orientation has been measured by tests such as the Guilford-Zimmerman Test of Spatial Orientation (see Eliot and McFarlane-Smith 1983) in which subjects are presented two views of a shoreline from the bow of a boat Subjects must determine the motion of the boat from the first view to the second view based on the corresponding change in shoreline Spatial orientation has been demonstrated to play a role in a variety of spatial tasks such as the acquisition of route knowledge during actual navigation (Pearson and Ialongo 1986), acquisition of survey knowledge during simulated navigation (Albert 1997), acquisition of survey knowledge under conditions of spatio-temporal discontinuity (Albert et al 1997), and map-reading comprehension (Gilmartin and Patton 1984). Spatial orientation may also play an important role in the use of GIS since GIS-users are often required to adopt new perspectives on 2-D and 3-D graphic representations such as a digital elevation model (DEM) In order for the GIS-user to make any spatial inferences regarding shape, pattern, or layout, where the orientation of the object is a factor, the user must adopt a new perspective, and therefore use aspects of spatial orientation ability

Spatial visualization is the ability to mentally manipulate, twist, or invert 2-D or 3-D spatial configurations (McGee 1979). Spatial visualization, also referred to as spatial manipulation (Carpenter and Just 1986), generally involves either the manipulation of a 2-D or 3-D spatial configuration in which there is movement among its internal parts (e.g Guilford-Zimmerman Spatial Visualization Test) or 2-D or 3-D mental rotation of an object in which all features within the object are static (e.g. Shepard and Metzler 3-D Cube Rotation Test; Eliot and McFarlane-Smith 1983) While spatial visualization has not been shown to be an important aspect of map reading (Pearson and Ialongo 1986) or simulated navigation (Albert 1997), it may be very important in the use of GIS. In particular, spatial visualization ability may be extremely useful in tasks such as map overlay, since this ability involves manipulation of internal parts of a stimuli (map layers) In essence, map overlay involves the comparison of individual spatial elements and the performance of a logical operation on those elements, hence manipulation. Spatial visualization may also be used in the rotation and geometric transformations of 2-D and 3-D graphic representation such as map layers and DEMs

A third possible spatial ability, spatial relations, involves analysing patterns, shape, layout, hierarchy, and linkage between individual stimuli within a visual configuration (Self et al 1992). Golledge et al (1995) suggested that this ability may be most widely used within the field of geography. However, it is seldom examined in psychometric spatial ability tests. This ability may be important in specific GIS tasks in which mental rotation is not involved, such as the identification of features, as well as the clusters to which features belong, and the recognition of spatial association (Self et al 1992).

4 Methods

The map overlay operation was selected since it is a fundamental GIS operation which requires spatial cognitive abilities to mentally visualize and manipulate spatial objects. In performing a map overlay function in GIS, the user may perform several cognitive tasks selecting the most appropriate operation (or series of operations) to achieve a specific result, visually verifying a map overlay process, and selecting the appropriate map layers to overlay While not every instance of using the map overlay operation requires these three cognitive activities, we believe that most GIS-users perform them on a substantial number of map overlays. Consequently, our experiment focused on these tasks

4.1 Subjects

A total of 127 subjects (51 female and 76 male) participated in the experiment Subjects were undergraduate students at the University of California at Santa Barbara, and were recruited from the psychology and geography undergraduate subject pools, and the Introductory GIS class. Subjects received partial course credit for participating in the experiment. The total time for subjects to complete the experiment was 50 minutes, they performed experimental tasks in groups of 15 to 30 students

4 2 Stimuli and Apparatus

Three paper and pencil tests were designed to measure performance on a variety of spatial cognitive tasks associated with the map overlay operation The design of a paper and pencil test was a deliberate effort to control for varying level of experience with specific software, hardware, and operating systems While this may sacrifice some measure of ecological validity, strict control of individual differences in computing experience was gained. The polygons used in the experiment were simple geometric objects, not containing any geographic or attribute information. This was done to focus the experiment on the fundamental task of cognitively manipulating spatial objects, not on the higher-level task of processing geographic and attribute data during the map overlay operation. As a result, the three tests used in this study were not intended to be a direct match with the actual tasks GIS-users perform, but rather to measure how well GIS-users were able to visualize and manipulate spatial objects given a set of logical operators, input map layers, and output map layers. We believe these tests tap into spatial cognitive abilities which are essential to the use of GIS, and the map overlay operation specifically.

Three tests contained a total of 16 overlay problems per test (for a total problem set of 48 overlays), which varied on three dimensions: number of polygon edges (three or five) × number of polygons per map layer (one or two) x logical operator ('and', 'or', 'xor', 'not'). For each test, subjects were given two of the following· input map layers, logical operator(s), or output map layer. For Test 1 (5-alternative forced choice), subjects selected the correct logical operator (see Figure 1), for Test 2 (4-alternative

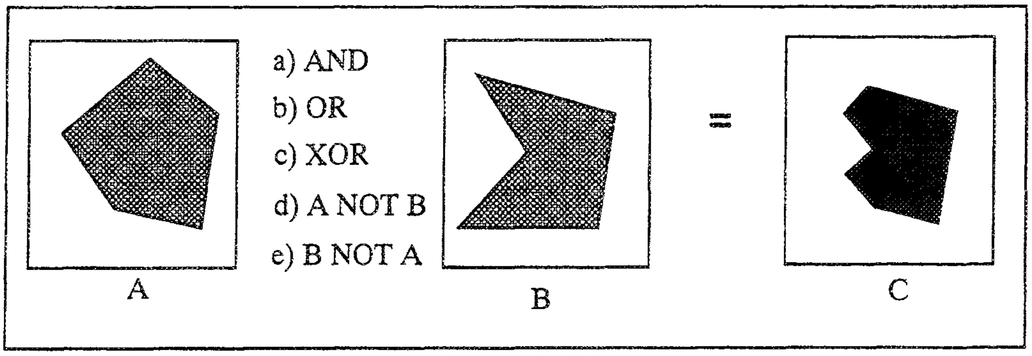

Figure 1 Example of Test 1 Subjects must select the correct logical operator

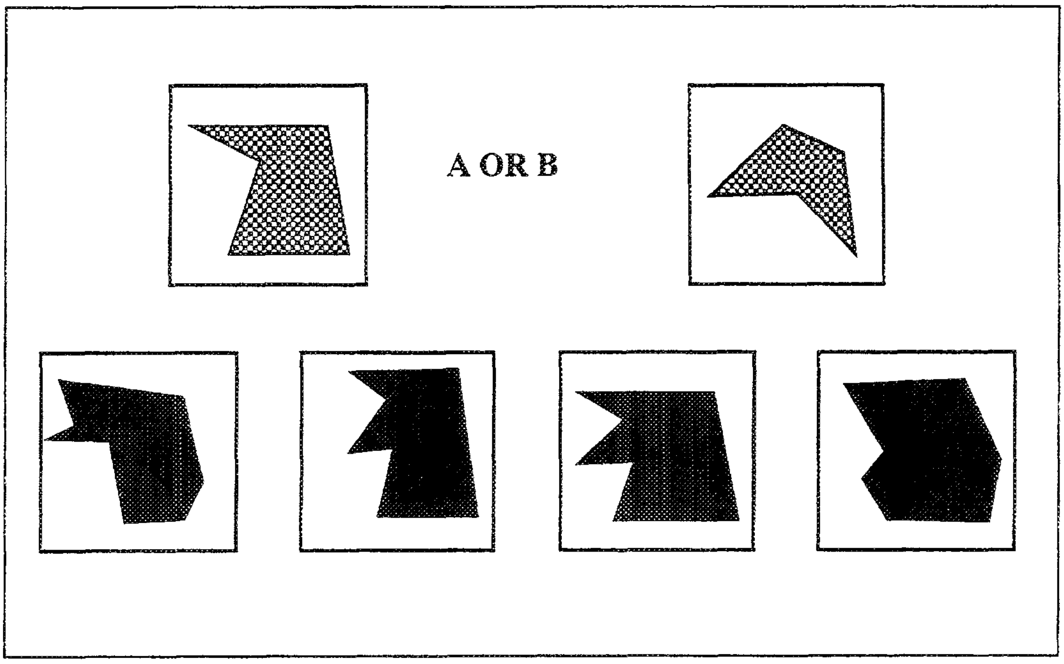

Figure 2 Example of Test 2 Subjects must select the correct output layer

forced choice) they selected the correct output layer (see Figure 2), and for Test 3 they selected the correct input layers (see Figure 3) The presentation of the overlay problems was randomized for each test. All subjects received the same random order of map overlay problems

4.3 Procedure and Design

At the start of the experiment subjects were shown examples of the four different Boolean logical operators used in the experiment Prior to beginning each of the three tests, subjects participated in a short practice session. For each test they were instructed to complete as many of the overlay problems as possible, without sacrificing accuracy A time limit of 12 minutes was set for each test since it is believed that both speed and accuracy are important factors in the effective and efficient use of GIS During all tests, examples of the various Boolean logical operators were displayed so memory for the

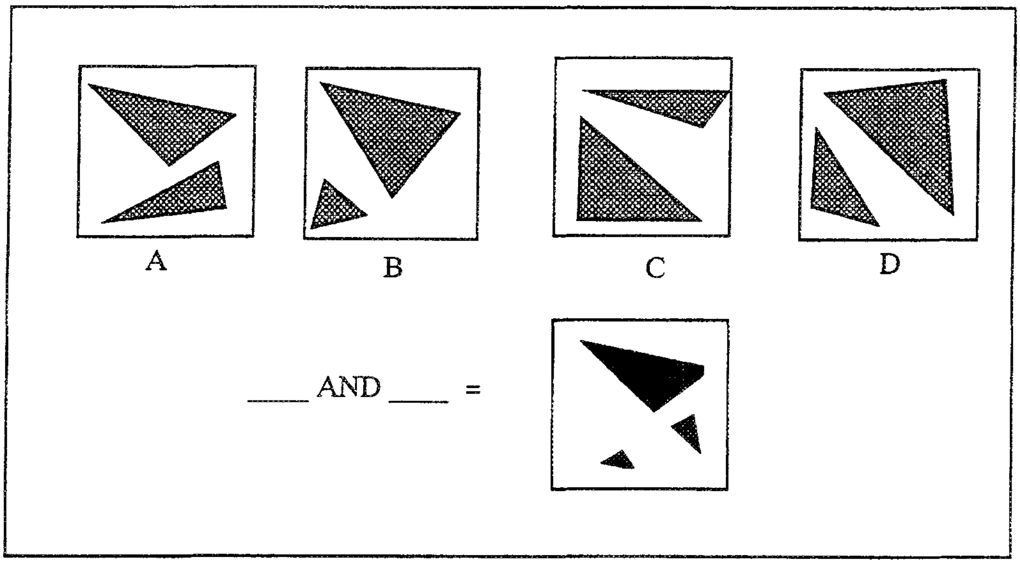

Figure 3 Example of Test 3. Subjects must select the correct input layers

different operators was not being tested. Performance was measured as the total number of questions correctly answered (n) minus the number incorrect (m) divided by the number of alternatives (a) minus 1 ($n - (m/a - 1)$). This performance measure was used to control for guessing. Therefore, a score of zero represents chance performance, while a score of 1.0 indicates perfect performance. For example, if a subject guesses on a four-choice alternative test with 16 questions, they should correctly answer four questions (by chance). Therefore, the score would be $4 - (12/3) = 0$. Following the experiment, subjects completed a questionnaire indicating their sex, age, class, and experience with GIS.

5 Results and Discussion

Subjects were randomly placed into one of three groups. Each group received all three tests, however, testing order was counterbalanced to control for possible order effects on performance for each of the three tests. The results of a multivariate analysis of variance did not provide statistical evidence that testing order affected performance on any of the three individual tests, $p > 0.05$ in all testing conditions. Therefore, data for all tests were used in the analysis.

Performance was analysed for the three map overlay tests (Figure 4). A within-subjects ANOVA provided evidence for a significant effect of test type on performance, $F(2, 260) = 41.74, p < .001$. Results from a paired-samples t-test indicated significantly better performance on Test 1 (selecting the logical operator) than Test 2 (selecting the output layer), $t(134) = 7.82$, $p < .001$. In addition, performance was significantly better on Test 3 (selecting the input layers) than Test 2, $t(134) = 9.63$, $p < .001$. There was not a significant difference in performance between Test 1 and 3, $t(134) = 1.14$, $p > 0.10$. Lower performance for Test 2 may not necessarily be due to any true differences in performing different map overlay tasks, but rather may be an artifact of the particular test since the distractors may have been more similar to the target than in the other tests. However, it should be noted that for all three tests, performance was

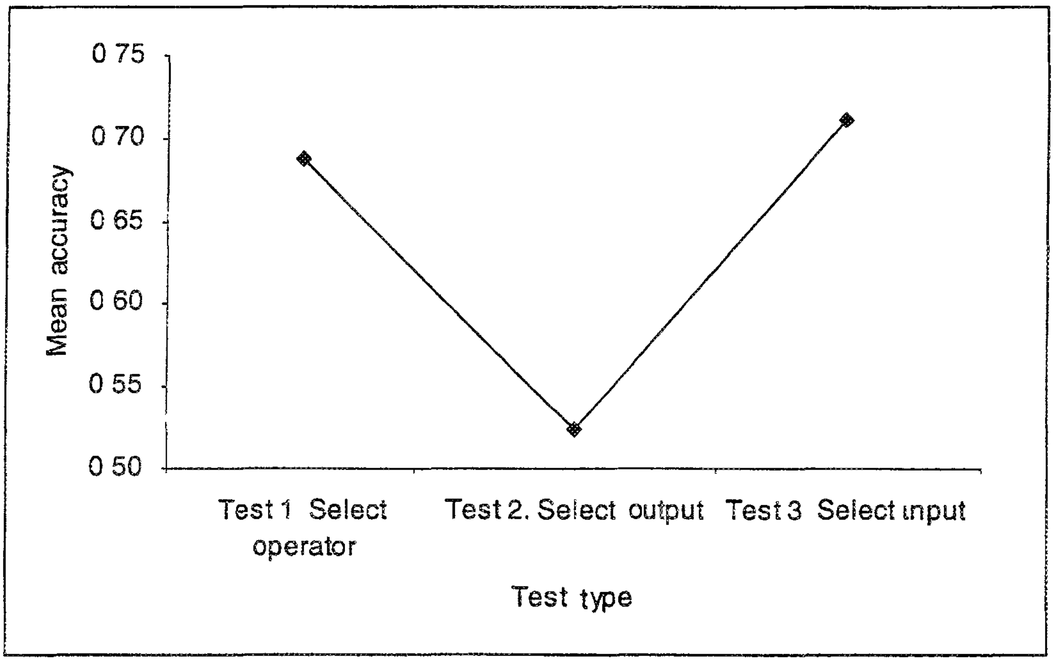

Figure 4 Main effect of test type on accuracy

significantly above chance (zero), indicating that subjects understood the objectives of each test and were able to manipulate spatial objects mentally.

Performance was analysed for the four types of logical operators (Figure 5) Results from a within-subjects ANOVA showed a significant main effect of logical operators on performance, $F(3, 366) = 34.27$, $p < .001$ Specifically, paired-sample t-tests revealed significantly better performance on 'or' operators than 'and' and 'not' operators, $t(134) = 8\ 77, 8\ 19$, $p < 0\ 001$, respectively In addition, performance was significantly better

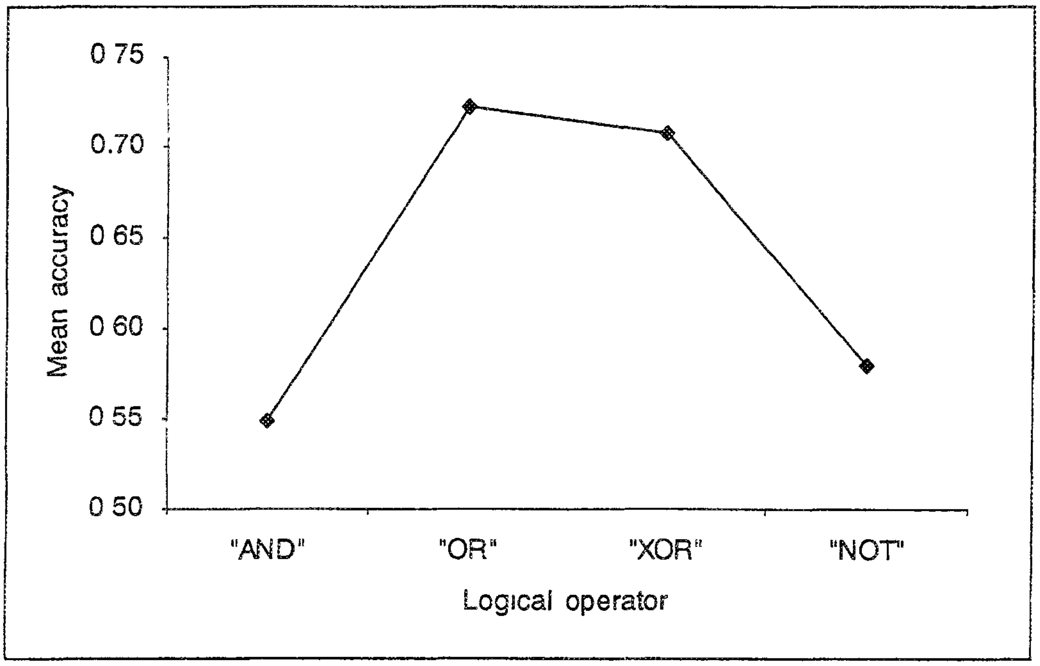

Figure 5 Main effect of logical operators on accuracy

on 'xor' operators than 'and' and 'not' operators, $t(134) = 7.67, 7.52, p<.001$, respectively. There was no difference in performance between 'and' and 'not' operators, and 'or' and 'xor' operators, $t(134) = 1.37, 0.99, p > .10$, respectively.

Performance using different logical operators may be attributed to the ease to which the same polygons in the input and output map layers may be visually compared and the number of steps required to achieve the desired results. This explanation is consistent with the results of this study. Relatively better performance on 'or' operators may be attributed to the relative ease of mentally adding or combining spatial objects since subjects may visually compare any part of the output layer with the input layers because the output layer must contain the entire set of input spatial objects. This is not the case for 'and' operators in which subjects are less able to visually compare the output and input layers since the output layer does not necessarily match the input layers. One might have expected similar performance on 'xor' and 'and' operators since these two types of operators are based on similar cognitive processes. However, this was not the case, possibly because the visual patterns created by 'xor' operations produced a more distinctive pattern than visual patterns created by 'and' operators. The 'xor' operation in most cases involves subtracting the interior of a polygon (if both polygons are located in the centre of the box), leaving the general shape of the polygon intact and thereby easier to identify. Conversely, the 'and' operation generally produces a small or series of small polygons located in the centre region (if the polygons are centrally located), which do not contain any distinctive features that can be associated with the original (input) polygons, thus making the original (input) polygons harder to identify. In the case of 'not' operators, relatively lower performance may be attributed to the additional step of taking into account the sequence of map layers (for example, 'A not B' is not equivalent to 'B not A').

Performance was also analysed for the number of polygon edges (Figure 6). Results from a paired-samples *t*-test showed that performance was not significantly different for overlays involving polygons with three and five edges, $t(134) = 1.20, p = .23$. This

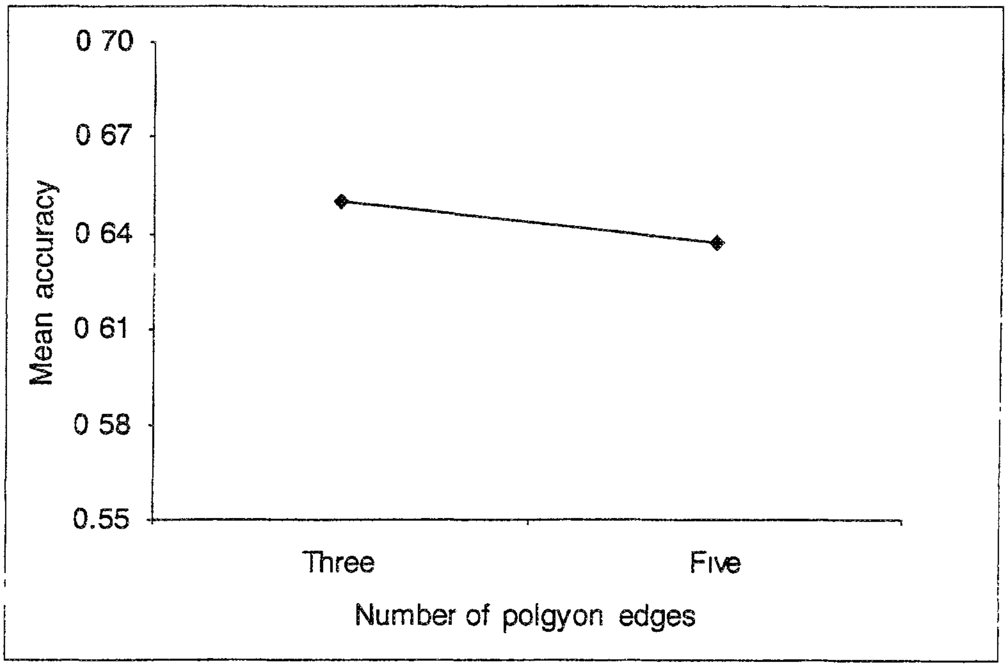

Figure 6 Main effect of the number of polygon edges on accuracy

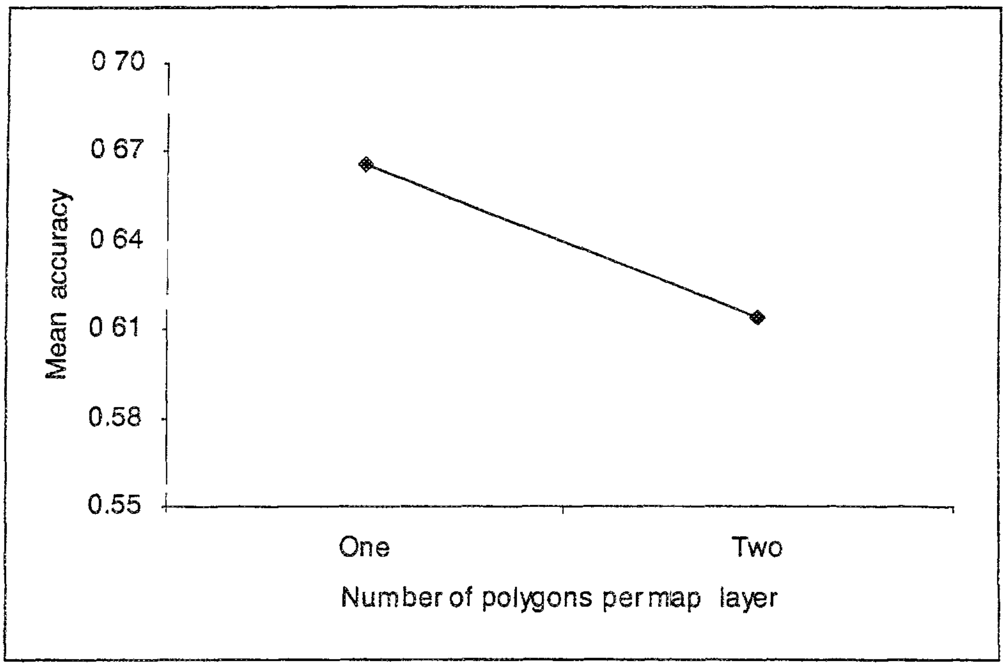

Figure 7 Main effect of the number of polygons on accuracy

finding suggests that subjects are equally proficient at mentally visualizing and manipulating spatial objects which vary in the number of polygon edges. This is surprising since one might assume that greater cognitive effort should be required mentally to visualize and manipulate more polygon edges. However, it is believed the visual distinctiveness of the five-sided polygons may have offset any additional cognitive load requirement, resulting in approximately equal performance between five-sided and three-sided polygons.

Performance was analysed for map layers containing a single polygon and map layers containing two polygons (Figure 7). Overall, performance was worse for map layers with two polygons, as compared with a single polygon, $t(134) = 4\ 70$, $p < 001$ Therefore, the number of discrete spatial objects appears to have more of an effect on performance than the number of polygon edges. Lower performance for two polygons per map layer may be attributed solely to processing multiple spatial objects, since visually distinctive patterns created by three- and five-sided polygons and different logical operators was controlled. Therefore, the number of polygons per map layer may be considered an aspect of overlay complexity since several objects must be stored in visual memory and simultaneously manipulated It may be easy to envision a point at which there would be too many polygons to process mentally. However, the user may simply choose a small area of the map layers to focus on to visually verify the results, and match with the input layers It would be interesting to identify various methods used mentally to visualize and manipulate a large number of polygons, since everyday GIS use involves map overlays containing hundreds or thousands of polygons

Results from a within-subjects ANOVA revealed a significant two-way interaction between logical operators and the number of polygon edges, $F(3,393) = 14\ 75$, $p < 001$ (Figure 8) A series of paired-sample t-tests revealed (1) better performance on five-sided polygons for 'or' and 'xor' operators, $t(134) = 5.52, 3.06$, $p < 001$; (2) better performance for three-sided polygons for 'and' operators, $t(134) = 3\ 73$,

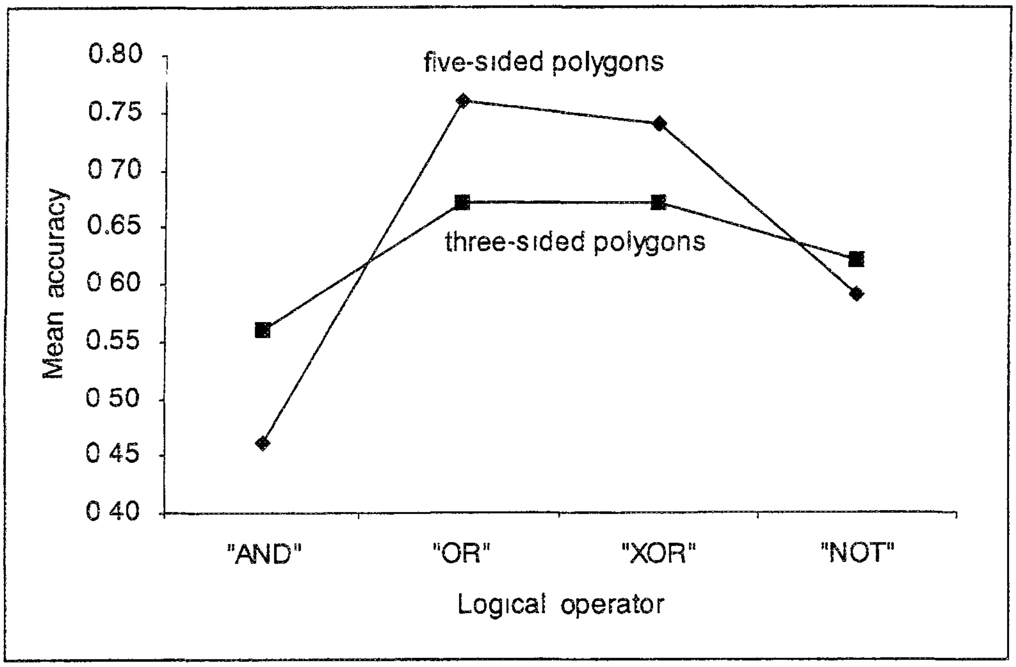

Figure 8 Interaction effect of logical operators and number of polygon edges on accuracy

$p < 0.001$, and (3) no difference in polygon complexity for 'not' operators, $t(134) = 1.33$, $p > 0.10$ These results suggest that relatively more complex shapes (as measured by the number of polygon edges) may be both easier and more difficult to overlay depending on the type of logical operator. These results are consistent with the previous explanation of visually distinctive patterns of polygons. Specifically, visually distinctive properties of polygons are generally better preserved with 'or' and 'xor' operators, and less preserved with 'and' operators (depending on the location of polygons within the map) This is reflected in these results since performance was better for five-sided polygons on the logical operators which better preserve the distinctive characteristics of the polygon ('xor' and 'or'), and worse for the 'and' operator which does not preserve the visual distinctiveness of the polygon. Overall, this finding reveals the sensitivity of mentally visualizing and processing the number of polygon edges with respect to the various logical operators.

A significant two-way interaction was also found between logical operators and the number of polygons, $F(3,393) = 18.00$, $p < .001$ (Figure 9). There was significantly better performance on single polygon layers for 'and' and 'or' operators, $p < 0.001$, but there was no difference in performance between single and multiple polygon layers for 'xor' and 'not' operators, $p > .10$ in both instances. The difficulty of performing an 'and' operator with multiple polygons may be due to a smaller and less visually distinctive output layer, as compared to a single polygon, thus making it more difficult to compare visually between the input and output layers Lower performance for multiple polygons with 'or' operators may be due to the constrained space in which the polygons were located. Since each map layer contained two polygons, the map output must contain four distinct polygons, resulting in a large amount of overlap between the spatial objects, providing few unique shapes to differentiate visually the polygons. Conversely, performance was nearly the same between single and multiple polygons for

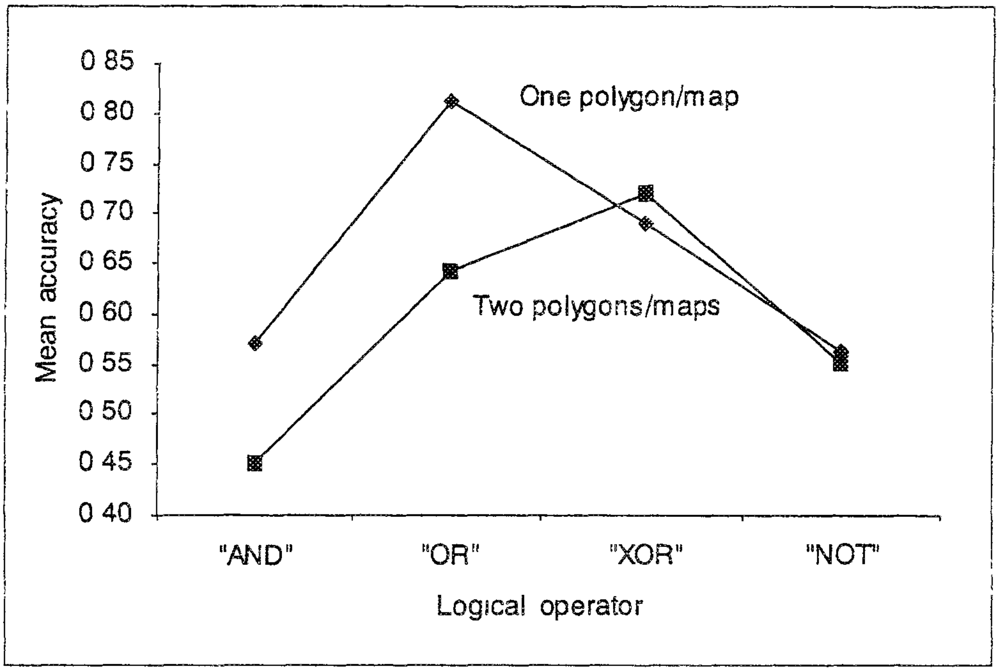

Figure 9 Interaction effect of logical operators and number of polygons on accuracy

'xor' operators Unlike the 'or' operator which did not allow for visually distinctive patterns to be recognized, the 'xor' operator was able to preserve the distinct visual characteristics of the polygons Together, these results show that the number of polygons in each map layer may be relatively easier or more difficult to process cognitively depending on the logical operator used

Performance was analysed for two specific subpopulations GIS-users/GIS non-users and males/females. Overall, there were no statistically significant differences in performance between GIS-users (n = 38) and GIS non-users (n = 96) for any of the test conditions or two-way interactions. There were also no significant differences in performance between males (n = 76) and females (n = 51) on any of the test conditions or two-way interactions, with the sole exception of better performance by males on 'not' operators, $F(132)$ = 41.6, $p =$ 04. However, in all test conditions and two-way interactions there was a trend for slightly better performance by males. The interaction between GIS experience and sex was not significant for any of the test conditions Perhaps future experiments with a larger sample size will provide further evidence on the significance of sex-related differences By almost all measures, it appears as though both males and females and individuals with and without GIS experience display approximately equal proficiency at visualizing spatial objects and performing mental operations on those spatial objects. Thus, at least some of the spatial abilities involved in the map overlay operation may be free of sex-bias and GIS experience. These results have significant implications for increasing the accessibility and use of GIS.

6 Conclusions

Spatial cognitive abilities used in the map overlay operation were analysed across four factors the type of task, logical operators, the number of polygon edges, and the number of polygons per map layer. Overall, subjects were able to perform successfully various map overlay tasks that varied in difficulty levels This was evidenced by performance significantly above chance in all test conditions Specifically, subjects were better at selecting the correct logical operators (Test 1) and map input layers (Test 3), as compared to selecting the correct output layers (Test 2). Subjects were better at performing map overlays involving 'or' and 'xor' operators as compared to 'and' and 'not' operators. There was no effect of the number of polygon edges on performance, but there was better performance on map overlays involving a single polygon on each map layer, as compared to two polygons per map layer There were significant two-way interactions between logical operators and the number of polygon edges and logical operators and the number of polygons per map layer There were no significant differences in performance between GIS-users and non-users for any of the test conditions or two-way interactions However, there was a non-significant trend for better performance by males in all test conditions and two-way interactions with only significantly better performance by males on 'not' operators

This study has three important contributions to make. First, this study has demonstrated that it is possible to examine spatial cognitive abilities which are directly relevant in the use of GIS. While GIS researchers and educators have suggested that spatial cognitive abilities play a fundamental role in the effective use of GIS (Nyerges 1995), this claim has yet to be proven experimentally. This study has shown that it is possible to develop a series of paper and pencil tasks which directly tap into the spatial cognitive abilities used in common GIS operations. The degree to which the testing methods correspond to actual GIS use is a central concern. Not only does the use of GIS depend on knowledge about the software, database, and project goals, but also on the ability cognitively to visualize and manipulate spatial objects. More specifically, map overlay involves knowing about various software functions, map layers, and the ability to visualize the results of various map overlays The tests used in this study were not meant to correspond directly to the actual tasks performed by a GIS-user, but rather the tests were designed to measure the spatial cognitive abilities performed during the map overlay operation. Obviously there are many instances when the GIS-user may not need to cognitively manipulate or visualize spatial objects in order to perform a map overlay function The GIS-user may perform many correct overlays based strictly on their understanding of the map layers and overlay functions. We believe the tests designed for this experiment offer a valuable way of assessing the ability to cognitively manipulate and visualize spatial objects within a GIS setting.

Second, the results of this study reveal that the complexity of performing the map overlay function may be partially attributed to the degree to which a visual correspondence can be made between the input and output map layers. In essence, when the same polygons can be easily identified in both the input and output layers, the map overlay is better understood However, when the polygons are not easily matched between the input and output map layers, greater cognitive effort is required. This pattern of results was evident in performance across the four logical operators Better performance for 'or' and 'xor' operators was attributed to the fact that these operators better preserve the shape of the polygons than the 'not' and 'and' operators (since most polygons were centrally located in the box). Also, better performance for five-sided polygons for 'or' and 'xor' than three-sided polygons with these same operators reflects this notion. The visually more distinctive five-sided polygons were more easily identified with the 'xor' and 'or' operators, despite the additional information which was processed (two extra edges per polygon). In addition, map overlays which require relatively more steps to achieve a desired result are cognitively more demanding For example, the use of a 'not' operator in which the order or sequence of input map layers affects the output map layer requires the GIS-user to mentally visualize and process both the sequence of input layers, and the contents in each of those layers

Third, this study examines whether specific subpopulations differ in their spatial cognitive abilities within a GIS context This study is among the earliest to test whether the often reported male superiority in spatial tasks is relevant in a GIS context Since it was found that males and females are about as equally able to manipulate spatial objects in the context of map overlay, this suggests that cognitive abilities do not selectively favour males or females. This is very important in trying to attract a greater number of women to careers which rely on the use of spatial abilities, including geographic information science In addition, the lack of a difference in performance between GIS-users and non-users suggests that many of the basic concepts of map overlay and its spatial cognitive requirements are easily apprehended by the general population, and not specific to GIS-users alone This may have significant ramifications as GIS is brought more into the mainstream computing environment

The type of tests designed in this study offers a new method by which GIS researchers can examine how GIS-users solve a variety of spatial problems, how different GIS tasks vary in levels of difficulty, and how individual's may vary in their ability to perform a variety of GIS tasks Future research should also investigate differences in spatial reasoning between novice and expert GIS-users and how the use of various GIS operations correlate with performance on traditional psychometric tests GIS developers may also benefit by identifying the cognitive requirements of various GIS tasks, enabling them to redesign GIS functions so that the cognitive load of the user is minimized. Finally, GIS educators may benefit by understanding the inherent complexity of specific GIS tasks, and whether certain groups differ in their ability to understand these tasks

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