Abstract

A map is frequently combined with a text to provide spatial and non-spatial information for learners. How a map and a text are combined and the characteristics of learners are keys for understanding successful learning. This study used a cognitive experiment to investigate spatial learning by explaining performance on a test of acquired knowledge with variables related to the learning environment and to individual differences of learners. Results indicate that having participants read a text beside a map produced the best performance. Participants were more successful at learning the information in the text and less successful at learning the information on the map. Performance was measured by accuracy, reaction time, and confidence measures; a standardized index for overall efficiency combined these measures. Performance was significantly related to individual difference variables measuring experience, verbal and spatial working memory capacity, 2D/4D digit ratio, and cognitive style. Sex and gender variables were not significantly related to variations in performance. In complex learning situations, as in processing a combined map and text, the expected verbal and spatial processing advantages of female and male learners may both produce positive results. In more complex cases, variables related to brain asymmetry, memory capacity, and cognitive style may provide more useful explanations of performance.

Keywords: spatial learning, map, text, individual differences, memory capacity, digit ratio, cognitive style

Résumé

On associe souvent du texte à une carte pour fournir des renseignements spatiaux et non spatiaux aux apprenants. La manière dont la carte et le texte sont associés et les caractéristiques des apprenants sont des éléments clés pour expliquer cet apprentissage. Dans l’étude, on se sert d’une expérience cognitive pour évaluer un apprentissage spatial et expliquer le rendement obtenu à un test sur les connaissances acquises en tenant compte des variables relatives au milieu d’apprentissage et aux différences individuelles d’un apprenant à l’autre. D’après les résultats, les meilleurs rendements sont obtenus quand les participants lisent le texte à côté de la carte. Les participants apprenaient mieux les renseignements contenus dans le texte et moins ceux de la carte. Le rendement a été mesuré en fonction de la précision, du temps de réaction et des mesures de confiance; un indice normalisé de l’efficacité globale combinait ces mesures. Le rendement était étroitement lié aux variables de la différence individuelle qui mesurait l’expérience, la capacité de la mémoire opérationnelle verbale et spatiale, le rapport numérique 2D/4D et le style cognitif. Les variables du sexe et du genre n’étaient pas liées de près aux variations du rendement. Dans des situations d’apprentissage complexe, comme lors du traitement d’une carte avec du texte, les avantages prévus relativement au traitement verbal et spatial pourraient produire des résultats positifs tant pour les apprenants que pour les apprenantes. Dans des cas plus complexes, les variables liées à l’asymétrie du cerveau, à la capacité de la mémoire et au style cognitif pourraient fournir une meilleure explication du rendement obtenu.

Mots clés : apprentissage spatial, carte, texte, différences individuelles, capacité de la mémoire, rapport numérique, style cognitif
Introduction

The interaction between a map and text has been studied using different assumptions about the dominant source of information. Some studies have focused on reading comprehension and whether the map can aid learning with text (Kulhavy, Stock, and Kealy 1993). Michael Verdi and Raymond Kulhavy (2002) argue that when sequentially learned, the two are partners that work together to aid the learning process. Others have suggested that the combination can impede learning when they compete for attention (Bunch and Lloyd 2006). Research on map–text combinations needs to place basic questions on learning performance within contexts that consider the effects of the learning environment and the characteristics of map learners.

Maps express spatial information in a variety of ways. A reference map, for example, uses map symbols to illustrate spatial relationships and meaning. Narrative texts provide additional descriptions of map features and their relationships. This study uses a hypothetical map of an island and three experimental methods for presenting narrative text. The purpose is to identify which method produces the most efficient performance when a novel map and text are simultaneously available. The methods used to present geographic information represent experiences one might encounter when learning about an unfamiliar place in a book or on a Web page. In this study, an efficient performance is defined as task scores indicating high accuracy, high confidence, and fast response time. Task scores that indicate low accuracy, slow response time, and low confidence reflect a negative performance.

Memory for Objects and Locations

Cognitive scientists make a distinction between object memory and location memory (Bellgowan and others 2009). Verbal processes in the left hemisphere encode categorical spatial information, and visual processes in the right hemisphere encode coordinate spatial information (Kosslyn and others 1998). Categorical spatial information is easier to learn but less exact; coordinate spatial information is more accurate but also more difficult to learn. Coordinate spatial information for a city indicates its horizontal and vertical locations on a map, while categorical spatial information for the same city would relate to its location in a specific region or along a particular river. Both types of information indicate where the city is on a map. Functional magnetic resonance imaging (fMRI) can identify regions of the brain associated with categorical and coordinate visual memory (Slotnick and Moo 2006; van der Lubbe and others 2006). Although there are separate systems for processing spatial and non-spatial information, these types of information are associated with one another in memory (Sommer, Schoell, and Buchel 2008).

Although the typical learner is capable of encoding verbal information using left-hemisphere processes and visual–spatial information using right-hemisphere processes, individuals may have these resources asymmetrically distributed within regions of the brain (Fenner, Heathcote, and Jerrams-Smith 2000). Evidence suggests that a complex mix of biological and environmental factors affects an individual’s spatial abilities (Casey 1996). Individual differences such as brain structure, gender, memory capacities, and cognitive styles are likely to affect performance in learning and recalling geographic information. Individual learners who favour verbal processing may be more efficient when reading text, while individual learners who favour visual-spatial processing may be more efficient when reading a map.

Asymmetrical Spatial Learning

Asymmetrical brains provide an advantage for map readers by representing characteristics of mapped objects and relationships among these objects simultaneously as category and coordinate information (Jager and Postma 2003). David Patton and Robert Lloyd (2009) found evidence supporting asymmetrical differences between participants who searched a small-scale map for well-known cities and those who searched for novel cities. Their results suggest that participants who searched for known cities encoded coordinate information, while those who searched for the novel cities encoded categorical information, and demonstrated a sex-related bias in encoding tendencies between female participants (categorical) and male participants (coordinate). The current study further examines asymmetrical learning using more complex map and text combinations that present opportunities to learn both spatial and non-spatial information.

Individual Differences of Map Learners and Performance

Any study involving map use needs to take into consideration the differences among the individuals who use the map. In this section, we review evidence that gender, working memory capacity, hand-digit ratios, and cognitive styles are likely to influence spatial learning.

GENDER IDENTITY OR SEX?

Numerous cognition studies have used sex as a measure of individual differences among participants (Halpern 2000; Kimura 2000). Some researchers have argued that a classification based on sex is limiting and that gender identification provides a more meaningful perspective for cognition studies (Hardwick and others 2000; Lloyd and Bunch 2008). Studies considering gender have demonstrated that female participants who score high on the
masculinity scale also score higher on a variety of spatial performance tasks (Signorella and Jamison 1986). It is also true that extended practice on spatial tasks can enhance overall performance and that female gender identity can guide interests that lead to such practice (Lloyd, Hodgson, and Stokes 2002; Casey 1996; Patton and Lloyd 2009). Deborah Saucier and others (2002) found that gender-role socialization mediates sex differences in spatial tasks requiring mental rotation. Lloyd and Bunch (2008) used the Bem Sex Role Inventory (Bem 1974) to measure masculinity and femininity scales for participants viewing a map of the US states; that study reported better performance for participants who scored high on both the masculinity and femininity scales, and higher accuracy for those who scored lower on both the masculinity and femininity scales. The current research considers the influence of gender identity on spatial learning involving map and text combinations.

WORKING MEMORY CAPACITY

Alan Baddeley’s (2003) multi-component model of working memory contains a component for processing visual information (the “visuospatial sketchpad”) and a separate component for processing verbal information (the “phonological loop”) that have a limited storage capacity. Cognitive load theory (CLT) explains how people use both visual-spatial and verbal information during learning and problem solving (Sweller 1988; Bunch and Lloyd 2006). A key proposition of CLT is that working memory has a limited capacity but connects to unlimited long-term memory (Sweller 1988; Baddeley 1998). Tests of working memory span partially explain variations in performance on real-world cognitive tasks (Fischer 2001; Cowan and Morey 2006). Lloyd and Bunch (2008) report a significant relationship between performance accuracy on a search task and the results of verbal- and spatial-memory-span tests. The current study uses working-memory-span tests to explore spatial learning with a map and text.

HAND–DIGIT RATIOS AND ASYMMETRICAL BRAINS

Cognitive abilities affected by sex hormones have both lifelong organizational and short-term activational effects on behaviour (Kimura 1989; Falter, Arroyo, and Davis 2006). Scott Bell and Deborah Saucier (2004), based on their study of activational effects, suggest that optimal performance on a spatial task occurs with moderate levels of testosterone; this moderate level is relatively low for men and relatively high for women. Catherine Gouchie and Doreen Kimura (1991) report the same pattern, with higher-testosterone women and lower-testosterone men exhibiting better spatial abilities.

Exposure to prenatal sex hormones affects asymmetries in the human body, including how the brain is structured (Manning and others 1998; Janowsky 2006). Researchers consider the ratio of the second digit to the fourth digit on the hand (the 2D/4D ratio) as a biomarker to identify brain asymmetry. Prenatal testosterone slows the growth rate of the left side of the brain while enhancing growth of the right side (Brosnan 2006); the length of the fourth digit (ring finger) is an index of prenatal testosterone exposure, and the length of the second digit (index finger) is an index of prenatal estrogen exposure. The 2D/4D ratio, therefore, provides an index of asymmetrical development of the brain hemispheres. Men generally have a significantly lower mean 2D/4D ratio than women (Loehlin and others 2006). Studies have also linked the 2D/4D ratio to the variation of spatial abilities (Coolican and Peters 2003; Csathó and others 2003; Falter and others 2006). Lloyd and Bunch (2008) report results indicating that the 2D/4D ratio interacted with both gender and working memory capacity to explain reaction time and accuracy in a search for target states on a US map.

COGNITIVE STYLES—EMPATHIZING AND SYSTEMIZING

Another promising way of looking at individual differences has been termed “cognitive style.”1 In broader terms, cognitive style might be thought of as the way in which a person approaches the world and solves problems. The origin of the “empathizing–systemizing” theory of psychological sex differences is in autism-disorder studies presented by Simon Baron-Cohen and colleagues. Empathizing and systemizing are two different dimensions measured by an empathy quotient (EQ) and a systemizing quotient (SQ) respectively (Baron-Cohen and others 2003; Baron-Cohen and Wheelwright 2004). People who score high on the EQ have a cognitive style that drives them to identify another person’s emotions and thoughts, while people who score high on the SQ have a cognitive style that drives them to analyse or construct systematic relationships in non-social domains. Both women and men show a range of variation on both EQ and SQ dimensions, but women score on average higher than men in empathizing and men higher than women in systemizing (Nettle 2007). Other studies (Billington, Baron-Cohen, and Wheelwright 2007; Focquaert and others 2007) have reported that, on average, those interested in the humanities favour an empathizing style while those interested in sciences favour a systemizing style, regardless of sex.

Studies on cognitive style that connect spatial learning with maps are rare. One exception (Billington, Baron-Cohen, and Bor 2008) considered participants with a range of scores on the SQ using an experimental task that elicited a conflict by having participants search for a target found at a global or local level (i.e., large letters made from small letters). They expected that an individual with a high systemizing style would be proficient in analysing the rules of a system. They report that participants with higher SQ scores appeared to focus their
attention on local details and performed the search task with more success when the target was at the local level. Map learners with high SQ scores may have more interest in and experience with information displayed on maps than map learners with high EQ scores do. The current research considers the potentially interesting relationships between cognitive styles and spatial learning using map and text combinations.

Research Design

The cognitive experiment used in the study had an initial learning phase followed by a testing phase (see Figure 1). All participants considered the same information in the text and map, but they used different learning methods. Three learning methods presented the information in different ways through auditory and visual sensory channels. The step after the learning phase tested participants on information available in the text and on the map. Accuracy, Reaction Time, and Confidence measured the Efficiency of performance. Accuracy is a traditional measure of learning success, but Reaction Time and Confidence have also been useful in understanding overall performance on spatial tasks (Lloyd and others 2002; Lloyd and Bunch 2003).

The Method used by each participant and the participant’s Sex were recorded. Participants also responded to tests that determined categories of Gender, working Memory, and cognitive Style. The lengths of the index finger (second digit) and ring finger (fourth digit) on the right and left hands determined each participant’s 2D/4D ratio.

PARTICIPANTS

Ninety university students were paid $10 each to participate in the study. The participant pool was divided evenly among female ($n = 45$) and male ($n = 45$) students. All participants were from a university’s student population and were 18 years of age or older.

LEVEL OF EXPERIENCE

Participants were either placed in a lower experience category by limiting their exposure to information about the map and text or placed in a higher experience category by increasing their exposure to information about the map and text. A strategy called “test-enhanced learning” provided more experience (Roediger and Karpicke 2006). As Mark McDaniel, Henry Roediger, and Kathleen McDermott (2007, 200) explain, “test-enhanced learning refers to the fact that taking an initial test on studied material enhances its later retention relative to simply studying the material and then taking a final test.” Shana Carpenter and others (2008, 438) have reported results for learning linguistic knowledge that support the hypothesis that “memory tests enhance learning and reduce forgetting more than additional study opportunities do.” The method used in the current experiment was to have an initial study session for both the lower- and higher-experience groups; the higher-experience group also took a practice test and then had a second study session. We assumed that the practice test would provide a context for the second study session that would enhance learning. The statements on the practice test were different from those on the final test but had a similar style and content. We assigned the two sets of statements randomly to the practice and final tests to balance their effect on performance.

THE EXPERIMENTAL MAP AND RELATED TEXT

The experimental map showed a fictional isolated island called the Isle of Dogs, bounded on the west by the Atlantic Ocean and on the east by the North Sea (see Figure 2).
Other areas on the island were four named provinces, shown in different hues. Each province was subdivided into a number of unnamed counties, with named larger cities and unnamed smaller cities. Other point symbols for several cities represented economic activities. Linear features on the map represented an unnamed highway system and named rivers.

The narrative text with the accompanying map discussed physical, cultural, and travel information associated with the Isle of Dogs (see Appendix). The text supplied both spatial and non-spatial information that in some cases was also available on the map and in other cases was novel information.

LEARNING METHODS

Three learning methods exposed the participants to both the map and the text, but in different ways. Study sessions had no time limits and proceeded at a pace set by the participant. Participants using the reading method had the map (Figure 2) available on the left of the screen and the text information on the right. Each study session presented the physical, cultural, and travel information in a random sequence controlled by the participant. Participants using the reading method were constrained to reading the physical, cultural, and travel information in only two random sequences representing one study session.

Participants would use the visual channel to process information from the map and the text (see Figure 1). CLT argues that learning may be constrained if two sources of information compete for a single channel under time constraints (Bunch and Lloyd 2006; Harrower 2007). Since participants using the reading method were not under a time constraint, they could visually and consciously attend to either the map or the text.

Participants using the listening method had the map (Figure 2) available on the left of the screen without any visible text information on the screen. Instead, the physical, cultural, and travel text played through audio in a random sequence controlled by selecting a “next” button. Since each individual recording continued playing when started by a participant, the information was available in fixed blocks of time. As in the reading method, participants using the listening method could hear the recording in only two random sequences per study session. The
listening method represented a less traditional method, but one that made the spatial and non-spatial information available in two separate channels (see Figure 1). CLT argues learning can be enhanced if information coming from two sources can be provided in separate audio and visual channels (Mayer and Moreno 2003; Bunch and Lloyd 2006; Harrower 2007). The ability to focus visual attention on the map and audio attention on the recorded text simultaneously could potentially enhance learning.

Participants using the rollover method initially viewed a map without text (Figure 2). The map, however, contained rollover buttons that revealed text information describing the physical, cultural, and travel characteristics of particular locations. At the same time, a recording of the displayed text played through audio. Participants could control access by rolling over buttons in any sequence, but they were limited to two sequences per button. The rollover method created an interactive map whereby participants could connect map locations with text information provided separately through visual and audio channels.

It has been reported that “difficulty in learning new concepts can be alleviated by making text more cohesive which makes readers less dependent on pre-existing knowledge” (Ozuru, Dempsey, and McNamara 2009, 239). Some researchers have also suggested that non-linear text presentations increase the cognitive load for audiences without prior knowledge (Amadieu and others 2009; Calisir and Gurel 2009). Since participants in this study had no prior knowledge of the target content, the less cohesive rollover method may have increased the cognitive load.

TESTING FOR KNOWLEDGE LEARNED

Participants evaluated statements presented on both the practice and final tests as true or false. The knowledge required to evaluate the statement was available with equal frequency from the text only, from the map only, or from both text and map. Some statements featured non-spatial information, and some featured spatial information. For example, the statement “The Isle of Dogs was uninhabited before 1022 AD” features non-spatial information that was only available from the text; the statement “The city of Kenly is west of the Lundy River” features spatial information that was available only from the map; and the statement “The Isle of Dogs has four provinces” is based on information both on the map and in the text. The initial statements had important featured information missing. For example, “The Atlantic Ocean is of the Isle of Dogs” would initially appear; the participant clicked on the statement after reading it, and the featured information “east” would then complete the statement, allowing the participant to determine the true/false evaluation. The reaction time clock started when the featured information appeared and stopped when the evaluation was completed. This procedure did not count the time required to read the initial statement as part of the response time.

Variables

**PERFORMANCE VARIABLES**

**Accuracy, Reaction Times, and Confidence** collectively measured performance on the final test (see Table 1).
These variables previously have measured different dimensions of performance with success (Lloyd and others 2002; Lloyd and Bunch 2003, 2005; Bunch and Lloyd 2006). We expected a positive performance to be accurate, fast, and confident. We expected a negative performance to be inaccurate, slow, and unconfident.

The experiment measured Reaction Time in milliseconds, Accuracy as percent correct, and Confidence as ratings on a scale of -100 to 100. These three variables combined to compute a standardized measure of learning Efficiency ($E_z$). Fred Paas and Jeroen van Merriënboer (1993) provide a method for computing and visualizing the relationship between two measurements – mental effort and performance. Their method computes $z$-scores for performance and mental effort, which are used to derive an instructional efficiency score ($E$). $E$ is the perpendicular distance between the $x$, $y$ coordinate locations of the $z$-scores and a diagonal line representing where $E$ is equal to 0.

We have adapted this method to include the computation of $z$-scores for the three measurements of Accuracy ($A_z$), Reaction Time ($RT_z$), and Confidence ($C_z$):

$$E_z = \frac{A_z - RT_z + C_z}{\sqrt{3}}$$

In this study, $E_z$ was measured as the perpendicular distance between the data point for an observation and the neutral line where $E_z = 0$ along the $x$, $y$, and $z$ axes. Efficient learning increases as $E_z$ becomes more positive and decreases as it becomes more negative. The $E_z$ score can be used as a final measure of overall learning success by combining and analysing Accuracy, Reaction Time, and Confidence (see Figure 1 and Table 1).

**VARIABLES RELATED TO THE LEARNING ENVIRONMENT**

The research design imposed three learning environment variables on the participants (see Table 1) and assigned each participant to a Method category. The variable Experience represents the level of experience acquired by each participant, and the Source of the information indicates the origin of information.

**INDIVIDUAL DIFFERENCE VARIABLES**

We measured individual differences among the participants in categorical form to serve as main effects in a statistical model (see Table 1). We recorded the Sex of participants and also measured each participant’s response to questions for the Bem Sex Role Inventory (Bem 1974) to measure Gender identity (see Table 1). Performance also relates to working memory capacity (Baddeley 2003). We used span tests to measure verbal and spatial working memory capacities and assigned each participant to a working Memory capacity category. Previous research has related asymmetrical brain structure and a preference for using verbal or spatial processes in problem solving to the ratio of the second and fourth digits of the hand (Manning 2002). We measured the lengths of the second and fourth digits on both hands and computed the average ratio for each participant; participants were then

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**Figure 4.** Performance variable means for learning environment variables: learning Method (a), level of Experience (b), and Source of information (c).
assigned to Low, Middle, or High categories based on their 2D/4D ratios (see Table 1). Simon Baron-Cohen (2002, 2003) has suggested connections among cognitive styles related to empathy and systemizing, sex differences, and task performance. We measured both the Empathy Quotient (EQ) and the Systemizing Quotient (SQ) for each participant and used the EQ and SQ scores to determine a cognitive Style category for each participant (see Table 1).

Analyses

The first set of analyses considered the relationship between Sex and the other individual difference variables: 2D/4D ratio, Gender, working Memory capacity, and cognitive Style. A multivariate analysis of variance (MANOVA) using three performance measurements as the dependent variables and the learning environment and individual difference variables as main effects was the final analysis.

SEX AND OTHER INDIVIDUAL DIFFERENCES

Figure 3 illustrates associations between categories of Sex (Female and Male) and categories for individual difference variables. The association between Sex and 2D/4D categories was significant ($\chi^2 = 9.6, p = 0.008$), and the distribution of Female and Male participants within the three 2D/4D categories suggests a meaningful pattern: Female participants have High 2D/4D ratios, while Male participants have Low 2D/4D ratios (see Figure 3a), a pattern supported by the findings of previous research (Loehlin and others 2006). The relationship between the 2D/4D ratio and spatial abilities, however, appears to be non-linear when considering Sex. It has been hypothesized that men and women in the Middle 2D/4D category would have better performance scores on spatial tasks (Sanders, Sjodin, and Chastelaine 2002; Falter and others 2006).

As one might expect, there was a significant relationship between the Sex and Gender categories ($\chi^2 = 15.2, p = 0.002$). Although Female individuals were most frequently associated with the Feminine category and Male participants with the Masculine category, both sexes appeared in all four Gender categories (see Figure 3b). These results indicate a significant overlap between the Sex and Gender categories.

Male and Female participants were distributed in a similar fashion within the working Memory categories (see Figure 3c). The data do not support a Female advantage for verbal working memory or a Male advantage for spatial working memory ($\chi^2 = 1.5, p = 0.670$).

Sex and cognitive Style were significantly related ($\chi^2 = 14.8, p = 0.002$). Female participants were more frequently represented in the Empathist and None categories, while Male participants were more frequently represented in the Systemist and Both categories (see Figure 3d). The Systemist category had fewer Female participants, and the Empathist category had fewer Male participants.

MANOVA RESULTS

The learning Method used by participants was found to be multivariate significant in explaining test performance.
(see Table 2). Between-subjects tests indicated that Method was significant in explaining Accuracy and Confidence but not in explaining Reaction Time (see Table 3). The expected pattern for a positive performance would have positive z-scores for Accuracy and Confidence and negative z-scores for Reaction Time. None of the learning methods indicated this pattern (see Figure 4a). The Accuracy of performance, however, strongly favoured the Read Method over the Listen or Rollover Methods. The Read Method also had the only positive mean for the Confidence variable. The Reaction Time means were not significantly different, but participants using the Read Method had the slowest mean time. The Efficiency index clearly points to the Read Method as superior to the Listen or Rollover Methods (see Table 2).

There could be several explanations for the dominance of the Read Method. First, participants were likely to have used the Read method more frequently in past experiences with books and Web sites. Second, the less familiar Listen and Rollover methods had lower Accuracy and Confidence means, even though separate audio and visual channels were equally available (see Figure 4a); although CLT argues that two sensory channels are likely to produce better results than one channel, this would be true only if the map and text competed for attention in the visual channel. With no time constraint, participants could switch their attention between the text and map to further consider any map locations mentioned in the text, and this would prevent competition in the visual sensory channel. With a time constraint, switching attention would not be possible, and competition in the visual sensory channel would increase the cognitive load. Third, the Rollover method presented text information within a non-linear structure that may have increased the cognitive load by substantially reducing the coherence of the narrative (Seufert 2003). The opportunity to look at the map, read text, and listen to text simultaneously may also have produced a general overload of information that reduced comprehension.

Main effect Experience was multivariate significant (see Table 2) and was univariate significant only for the Confidence variable (see Table 3). A positive performance pattern was found for the High Experience category, while a weak negative performance pattern was found for the Low Experience category (see Figure 4b). The z-scores for Accuracy and Confidence were positive for the High

<table>
<thead>
<tr>
<th>Variable</th>
<th>Measurement Form</th>
<th>Expectation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent</td>
<td>Continuous</td>
<td>Measures learning performance</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Percentage of correct responses</td>
<td>Positively related to performance</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>Milliseconds</td>
<td>Negatively related to performance</td>
</tr>
<tr>
<td>Confidence</td>
<td>Scale (−100 to +100)</td>
<td>Positively related to performance</td>
</tr>
<tr>
<td>Efficiency ($E_z$)</td>
<td>Standardized combined effects of Accuracy, Reaction Time, and Difficulty</td>
<td>Positive values = more accurate, faster, and more confidence; Negative values = less accurate, slower, and less confidence when recalled</td>
</tr>
</tbody>
</table>

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category and negative for the Low category, but Reaction Time means were virtually zero for both Low and High Experience categories. The Efficiency index indicated a relatively small advantage of High over Low Experience (see Table 2). It is no surprise to find that added Experience resulted in elevated levels of performance, especially since other studies have also found that practice tests enhance learning (McDaniel and others 2007).

Main effect Source was marginally multivariate significant (see Table 2). Between-subjects tests indicated a univariate significant difference only for the Accuracy variable (see Table 3). A positive performance pattern was found for the Text category, while the Map category showed a negative performance pattern (see Figure 4c). The Both category means had a positive z-score for Confidence and a negative z-score for Reaction Time, but the Accuracy mean had the wrong sign for a positive performance. The Efficiency index indicates Text as the best Source for information and the Map as the worst Source (see Table 2).

Individual difference effects are 2D/4D ratio, working Memory capacity, cognitive Style, Sex, and Gender. The main effect 2D/4D ratio was multivariate significant (see Table 2). Between-subjects tests indicated a univariate significant difference only for the Confidence variable (see Table 3). None of the 2D/4D ratio categories indi-
cated a positive or negative performance pattern (see Figure 5a). The best Efficiency score was associated with the High 2D/4D category (see Table 2).

The significance of the 2D/4D ratio effect produced an unexpected result (see Table 2): the best overall performance on the final test was associated with the High category. The 2D/4D ratio correlates with an asymmetrical development of the processes in the right and left hemispheres of the brain through exposure to prenatal hormones. Earlier studies have suggested a non-linear relationship between the 2D/4D ratio and spatial abilities, leading to the expectation that the Middle category might be associated with superior task performance. The current experimental task involved learning information rather than performing a perceptual task; the association of the High 2D/4D ratio category with higher levels of performance would appear to indicate that verbal processes in the left hemisphere were more useful for the experimental task.

The main effect for working Memory capacity was multivariate significant in explaining Accuracy, Reaction Time, and Confidence, and displayed a significant difference for the Reaction Time and Confidence variables (see Table 3). None of the working Memory capacity categories indicated an ideal positive or negative performance pattern (see Figure 5b). The Efficiency scores produced an interesting pattern for the working Memory capacity categories (see Table 2): the Verbalist category had the only negative value.

Working Memory capacity was independent of Sex and had the strongest effect on performance (see Figure 3 and Table 2). The Dual category was associated with the most positive overall performance on the final test. Since participants had better-than-median Spatial and Verbal working Memory capacity, this might be expected. The very negative performance associated with the Verbalist category connected to a very slow mean Reaction Time and a very low mean Confidence (see Figure 4). It is possible that a higher capacity for working with verbal information and a lower capacity for working with spatial information resulted in a tendency for these participants to focus their attention on processing verbal information, which may have been a disadvantage in a learning task involving a map and large amounts of spatial information.

The main effect cognitive Style was also multivariate significant (see Table 2). Between-subjects tests indicated a univariate significant difference only for the Confidence variable (see Table 3). The Systemist Style indicated the pattern for a positive performance, and the Empathist Style a pattern for a negative performance (see Figure 5b).

Table 3. Univariate significance between-participants test for significant differences using standardized Accuracy, Reaction Time, and Confidence individually as dependent variables.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Accuracy F Statistic (Probability &gt; F)</th>
<th>Reaction Time F Statistic (Probability &gt; F)</th>
<th>Confidence F Statistic (Probability &gt; F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning Method (Listen, Read, Rollover)</td>
<td>49.0 (0.000)</td>
<td>0.327 (0.721)</td>
<td>4.7 (0.010)</td>
</tr>
<tr>
<td>Level of Experience (Low, High)</td>
<td>2.4 (0.125)</td>
<td>0.001 (0.978)</td>
<td>9.3 (0.003)</td>
</tr>
<tr>
<td>Source of information (Map, Text, Both)</td>
<td>3.8 (0.023)</td>
<td>2.3 (0.101)</td>
<td>1.2 (0.289)</td>
</tr>
<tr>
<td>Sex (Female, Male)</td>
<td>0.114 (0.736)</td>
<td>0.141 (0.708)</td>
<td>2.6 (0.109)</td>
</tr>
<tr>
<td>2D/4D Ratio (Low, Middle, High)</td>
<td>0.8 (0.464)</td>
<td>0.054 (0.947)</td>
<td>6.6 (0.002)</td>
</tr>
<tr>
<td>Working Memory capacity (Dual, Spatialist, Verbalist, Neither)</td>
<td>0.84 (0.472)</td>
<td>8.9 (0.000)</td>
<td>8.1 (0.000)</td>
</tr>
<tr>
<td>Gender (Androgynous, Masculine, Feminine, Undifferentiated)</td>
<td>1.2 (0.315)</td>
<td>2.3 (0.076)</td>
<td>1.6 (0.186)</td>
</tr>
<tr>
<td>Cognitive Style (Both, Systemist, Empathist, None)</td>
<td>1.5 (0.227)</td>
<td>1.2 (0.300)</td>
<td>5.6 (0.001)</td>
</tr>
</tbody>
</table>
These two categories were also associated with the most positive and negative Efficiency scores (see Table 2). Cognitive Style was a significant effect, and, as expected, the Spatialist category was associated with the best positive performance (see Table 2). The means for the Spatialist category also showed a pattern of high Accuracy, fast Reaction Time, and high Confidence (see Figure 5c). This result supports the argument that cognitive style may play an important role in models explaining spatial learning.

The remaining individual difference effects, Sex and Gender, were not multivariate significant (see Table 2). Between-subjects tests also indicated no univariate significant differences for Sex or Gender categories (see Table 3). The nature of the learning task is one possible explanation for this lack of significance: several studies have shown a male advantage for naming places on world maps and a female advantage for tasks involving the recall of object locations in a spatial array (Dabbs and others 1998; Voyer and others 2007). The tasks for this experiment required learning both spatial and non-spatial information, very different from the previous studies, which have focused on isolating cognitive processes by task and sex. Other studies have also demonstrated a male advantage on visual tasks and a female advantage on verbal tasks (Halpern 2000; Kimura 2000). In this study, participants needed to use both visual and verbal processes to acquire information from the text and map. The expected advantages for female and male learners may ultimately have balanced out in considerations of overall performance because each group was required to consider both types of information. Gender was marginally significant (see Table 2). It is interesting to find that the Gender category Undifferentiated showed the most positive Efficiency score and the best overall performance.

Conclusions

Both learning-environment and individual-difference variables affected map learning. We assumed that the ideal positive performance would be accurate, fast, and confident; for the eight “winning” categories having the highest Efficiency for each effect (see Table 2), only half had collective ideal z-score mean patterns (i.e., positive values for Accuracy, negative values for Reaction Time, and positive values for Confidence). Three of the four that did not show the ideal pattern (Read Method, High 2D/4D ratio, and Undifferentiated Gender) had relatively slow Reaction Time means. Although it seems reasonable to consider an accurate, fast, and confident performance as the ideal positive pattern, accurate and confident performances also occur with slower reaction times. This might be the case if the information needed to evaluate a statement as true or false is voluminous, not well organized in memory, or not completely coded. Reaction times for simple tasks such as searching visual displays or for complex athletic performances are known to decrease with practice (Wilson, MacLeod, and Muroi 2008; Yarrow, Brown, and Krakauer 2009). The time needed to search one’s memory for the information learned from the experimental map and text is also likely to decrease with more experience.

There was no clear expectation as to which learning Method would produce the best performance on the final test. The more traditional method of acquiring new information (i.e., reading a text with a map) clearly produced the best performance (see Table 2 and Figure 4a). A familiarity advantage over other methods may partially explain the success of the traditional method, but its success may also be related to constraint differences between the Read and Listen Methods and coherence differences between the Read and Rollover Methods.

Experience and test performance should be positively related. This common-sense expectation was verified (see Table 2 and Figure 4b). The significant difference between the two Experience categories also supports the use of a practice test to boost learning when study time is limited. It was expected that the Both category would be the Source of information associated with the best performance. This expectation stemmed from the idea that redundant information in the text and on the map would increase the likelihood of successful learning. The Both category did have a positive Efficiency value, so this expectation may be correct; however, the Text Source had the highest Efficiency value. A simple explanation for this advantage relates to the nature of information in the Text-only category. Information available in the Text and on the Map was spatial information, while information available only in the Text was non-spatial information. Learning non-spatial information is apparently easier than learning redundant spatial information. The difficulty of learning spatial information may also explain the low Accuracy, low Confidence, and slow Reaction Time means for the Map Source category (see Figure 4c). Finally, participants may have found it easier to judge what was worth learning from the text than to decide what was worth learning from the map.

In general, women have an advantage in processing verbal information while men have advantage in processing visual-spatial information. Men also tend to score higher on tests of geographic knowledge, while women are better at learning the locations of objects in a space (Zinser, Palmer, and Miller 2004; Voyer and others 2007). Sex, however, was not a multivariate significant effect explaining performance in the present study (see Table 2). Because the information to learn was both on a map and in a text, the reported female and male advantages on previous isolated tasks may have been neutralized.
The literature indicates that men with higher-than-average 2D/4D ratios and women with lower-than-average 2D/4D ratios perform better on some spatial tasks, such as mental rotation and navigation (Coolican and Peters 2003; Csathó and others 2003). An expectation that participants in the Middle of the 2D/4D ratio distribution would also perform better on the current experimental learning task proved not to be correct. Individuals with High 2D/4D ratio have asymmetrical brains favouring systems in the left hemisphere. This provided a clear advantage in learning the map and text. Systems processing verbal and categorical spatial information were more important for the current learning task than right-hemisphere systems that support perceptual tasks. This finding indicates that asymmetrical brains may have an advantage for a range of spatial tasks, but not always in the same way.

Gender was not a multivariate significant effect in considering performance variables (see Table 2). The same argument as to why Sex was not significant may also apply to Gender: if participants in the Masculine category had better spatial abilities while participants in the Feminine category had better verbal abilities, the separate advantages may have cancelled each other out for the complete task. The fact that the Undifferentiated Gender category showed the highest Accuracy mean also supports this notion.

Larger working Memory capacity should aid performance. This hypothesis was generally supported for the current task, as the Dual category had the highest Efficiency score (see Table 2). Given that both spatial and non-spatial verbal information were available to learn, it seems reasonable that additional verbal and spatial working Memory capacity would be beneficial.

The nature of the experimental task suggested that a cognitive Style that focuses on understanding how systems work would be superior to a cognitive Style that focuses on other people’s emotions and thoughts. The multivariate significance of the cognitive Style effect and the high Efficiency score for the Systemist category support this expectation (see Table 2).

Experimental research that considers environments that reflect real situations faced by map users should be interesting to those interested in how people learn with maps. Future studies should consider a range of learning methods and how such methods interact with various individual-difference variables and spatial tasks. For example, tracking eye movements could supply data on what type of information attracts attention and for how long (Holsanova, Holmberg, and Holmqvist 2009). The current study focused on examining explicit map-learning tasks that closely resemble the learning environment found in most typical classrooms. Future studies might expand this contribution to include an examination of how the individual differences of learners and map tasks influence implicit learning.

Experimental research should also interest those concerned with the design of maps for use by map readers with special needs (e.g., tactile maps). It should also be possible to design maps for map readers with special advantages. Considering the effects of individual differences on performance will help in identifying less obvious needs and advantages for particular map types. In the future, it may be possible to systematically design maps tailored specifically to meet the needs of targeted age groups, map-reading levels, or cognitive styles. Maps designed to fit the cognitive profiles of users could provide more certainty about their effectiveness. The cycle of experimentation, exploration of instructional methods, assessment of performance, and modification of map designs would eventually lead to improved instruction, map learning, and map-design protocols.

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Notes

1. The term “style” is used in other contexts – for example, learning style based on a preference for using visual or verbal information (Graf, Lin, and, Kinshuk 2008).

2. Names of variables in the text appear in bold type; categories of these variables appear in italics. For example, Female and Male are categories of the variable Sex.

References


(Continued)
Appendix: The Text Supplying Physical, Cultural, and Travel Information about the Isle of Dogs

Physical. The Isle of Dogs is located between the Atlantic Ocean and the North Sea. The island got its name from the canines left on the island by passing Viking raiders. Rivers flow from the central highlands to the sea in three of the provinces. The English established the first permanent settlement at the mouth of the Annan River in 1022 AD. The climate is warm in the summer and cold in the winter. Storms from the Atlantic Ocean provide frequent and high levels of precipitation.

Cultural. The modern island has four provinces. Nussex has the smallest population and 3 counties and Essex has the largest population and 5 counties. Trent, the capital city, is centrally located in Essex and is the main seat of government. Other major cities are Kenly in Sussex that supports a thriving fishing industry, Wells in Wessex that excels in manufacturing and Alban in Nussex, that is the home of a growing recreation trade.

Travel. The island has a simple highway system that connects the towns and cities. There is an excellent and inexpensive bus system serving the entire island. Cars can only be rented at the airport. Travelers coming by ship generally come through the port of Wells while those arriving by air land at the airport near Trent. Travelers from outside of Europe will need to show a passport. Hotel rates are highest in Trent and less expensive in other locations.