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Evidence for different strategies in an indoor navigation task.

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Sammendrag

Spatiale evner bestemmer hvordan vi løser hverdagslige problemer. Tidligere forskning har oftest sammenliknet ferdighetene til ulike grupper individer, uavhengig av de underliggende prosessene. Målsetningen med denne studien var å forklare individuelle forskjeller i lys av ulike strategier som benyttes ved spatiale utfordringer.

Ferdighetene til universitetsstudenter (n=256) ble målt ved småskala-tester ved hjelp av Vandenberg-Kuse Mental Rotations Test, The Paper Folding Test and The Card Rotations Test. Tjuetre av de med best resultater og 25 av de med dårligst resultater ble valgt ut for videre testing med en computeroppgave av mentale rotasjoner og en Stroop interferenstest. I tillegg ble deres spatiale ferdigheter målt i en innendørs navigasjonsoppgave.

Vi predikerte at individuelle ferdigheter i småskala-testene avhenger av ”selective decoding”. Dette gjør det mulig for deltakerne å ignorere irrelevant informasjon i navigasjonsoppgaven i ulik grad. Oppgaven favoriserte bruk av en holistisk spatial strategi og var assosiert med ”selective decoding”. Likevel viser resultatene en alternativ strategi basert på detalj-kunnskap fra miljøet. Denne straegien syntes å være uavhengig av den holistiske strategien og var ikke relatert til gode navigasjonsferdigheter.

Abstract

Spatial abilities determine our approach to a variety of everyday tasks. Previous research has mainly compared the spatial performance of different groups of participants, regardless of the underlying processes. The aim of this study was to explain individual differences by means of the different strategies employed in spatial problem solving.

The performance of university students (n=256) was measured in small scale tests using the Vandenberg-Kuse Mental Rotations Test, The Paper Folding Test, and The Card Rotations Test. Twenty-three of the highest and 25 of the lowest performers were selected and further tested with computerized mental rotations- and Stroop interference tests. In addition, their large scale spatial abilities were explored in an indoor navigation task.

We predicted that individual performance on the small scale tests may depend on selective decoding allowing successful performers to ignore irrelevant information in the navigation task. The task did encourage the use of a holistic spatial strategy. Nevertheless, the results revealed alternative strategy based on the detail knowledge from the route. This strategy appeared to be independent from the holistic strategy, and unrelated to successful navigation performance.

Preface

The thought behind this project was to investigate spatial abilities in the way each of us experience them; as an individual skill enabling us to relate to and interact with our physical surroundings.

The two test situations of this study are strikingly different. The paper and pen tests on one hand were administered to groups of students in the minimalistic environments of an auditorium. The tests leave no doubt about the nature of the presented problems and the scoring of the tests are as standardized as the tests it selves. The manipulating of the small geometric object of the tests is not easily recognized as an everyday challenge.

The orientation task on the other hand is based on a situation easily recognized. Navigating in an unfamiliar building and at the same time looking for objects, could be compared to shopping in a supermarket you have never been to. The test environment was loaded with stimuli; the school was packed with colors, furniture, toys and equipment that easily could distract the participants from the tasks.

I hope the reader will find it fascinating to think of the fact that these to situations require some of the same abilities. And that the combination of the results from very different tests can enlighten spatial abilities and the contribution of different cognitive processes.

This thesis would never have been possible without my supervisor, Susanne Wiking, who has stood by me “for better and for worse”. I am grateful for all the aid and support she has generously provided. She has been involved in most steps of the project. The data collection of the second phase of the study would have been very difficult to manage by myself, and she willingly stepped in. The data analysis seemed at one point overwhelmingly, so she patiently explained and guided the steps. She also financed the rewarding of the participants.

I am also grateful to the principal of Prestvannet skole for the trust and letting me use the building for the purpose of this study.

I am astonished by the participants. They willingly used time and recourses to make this study possible. I am particularly impressed by those who showed up on a Sunday morning at a place they had never been to and spent one hour trying their best, knowing that the reward would be a coffee and a muffin! Luckily they reported to enjoy it!

At last I will thank my family who contributed from the side line as secretaries and cheered supportively whenever it was needed.

Anne-Karine Markeng Melsom

Susanne Wiking

Spatial abilities are crucial for relating to geometric and physical properties like distance, size, speed and weight. It is widely accepted that spatial abilities are part of intellectual abilities in general. Many everyday tasks will benefit from these skills and for some professions these skills are selective criteria for recruitment (aviators, architects, etc.).

Spatial competence is closely connected to how we process visuospatial information. This kind of information is visual in nature and has spatial properties. The skill is defined as part of our working memory (WM) capacity. According to the multicomponent model of WM, the visuospatial sketchpad is specialized to maintain and manipulate visual and spatial information (Baddeley & Hitch, 1974). WM performance relies on the visuospatial sketchpad to guide visual and spatial attention (Baddeley & Logie, 1999; Repovŝ & Baddeley, 2006). Complex cognitive tasks like visual search seem to require the additional involvement of WM resources related to the executive functions (Han & Kim, 2004). Several interference studies conclude that executive processes are crucial for prioritizing between relevant and irrelevant information (eg. Woodman & Luck, 2004). This attentional control enables us to focus, divide and switch attention between concurrent tasks (Repovŝ & Baddeley, 2006). The cognitive research perspective aims to identify the universal processes used in solving different spatial tasks. Limitations in these abilities have mainly been explained as a result of general capacity problems, characterized by the involvement of different or concurrent cognitive systems.

Regardless of the way in which WM is involved in visual selective attention, most researchers agree that the visuospatial information in focus needs to be stored in WM as mental representations. Representations are required for the space, the objects in it and the relationship between objects (Halpern & Collaer, 2005). Different tests are continuously developed and refined to explore how memory, visualization, attention and mental representations, among others, all are part of our ability to process spatial information. There are different approaches to investigate the nature of spatial abilities, but they are all based on the idea that the individual`s performance will be measured and evaluated.

Two rather independent test situations have invaded the field of spatial abilities. The most common one makes use of standardized paper and pen tests, later called *small scale* tests (SS). In recent years, different navigation tests and orientation tasks have contributed to new insight. Whether the test is conducted indoor or outdoor, they represent another dimension into the spatial challenge, and they are called *large scale* tests (LS).

The present study includes both small and large scale tests. In the ability screening phase of the study, three internationally established small scale tests were presented to the participants. The second phase, the applied performance phase, includes a large scale indoor navigation task, as well as a computerized mental rotations test and a Stroop interference test. Participants in the second phase were recruited from the best and the poorest performers of the screening phase. The ability to focus on target information according to a complex visual search task has been of particular interest. One of the aims of the study was to investigate the possibility that different attentional control can result in different spatial strategies. The findings from the two steps of the study will be discussed both separately and in light of each other.

The following section offers a characterization of small scale- and large scale tests in order to establish how they differ, to what extent they depend on common basic capacities or processes and in what way each of them can contribute to an understanding of spatial abilities and performance. The concepts of individual differences and strategies are reviewed thereafter.

Small scale tests and -abilities

Many studies have attempted to describe the specific spatial factors that constitute spatial abilities. Tests were often designed to investigate one or a few of these spatial factors at a time. In the psychometric tradition there has been a widespread use of small scale (SS) tests like paper and pen tests or tasks with objects on a table, conducted in a laboratory-type setting. Performance on these tests requires mental manipulations of small figural stimuli such as geometric shapes, blocks or cards. Montello and Golledge (1999) distinguished between figural, vista and environmental space. Figural space is small in scale relatively to the body and external to the individual. It includes both flat pictorial space and volumetric object space. It can be apprehended from a single viewpoint. Vista refers to the space that can be larger than the body, but still can be visually apprehended from a single spot. An example would be the room you are sitting in. Environmental space must be apprehended through different viewpoints and large enough to surround the individual and extend even further. The spaces of a building or a town are typical examples.

From one disciplinary perspective, spatial ability can be divided into three domains; spatial perception, mental rotation and spatial visualization (Linn & Peterson, 1985). The basis for this division is closely connected to the use of traditional paper and pen tests. Some of the tests are aimed at gauging the ability to mentally rotate a three-dimensional object which is presented two-dimensionally. Others are measuring factors like visualization and tap into the ability to distinguish a simple figure presented against a complex background. Spatial perception refers to the ability to sense verticality and horizontality (e.g. gravitational force).

In the understanding of individual differences in spatial ability this factor-analytic approach has some serious deficits. The model is based on the belief that everybody uses the same strategy for solving the same task. However, by studying different aspects of spatial ability one by one, the opportunities to reveal any relations between the different factors are reduced.

Large scale tasks and -performance

In large scale (LS) spatial situations, the individual plays an active role and the relative position and viewpoint changes in accordance to the locomotion of the person. While SS tests require an interaction, LS tests are based on participation. Most LS tests take place either indoor in a building or outdoor in a city or in open/free nature. Virtual reality (VR) tasks may share some common features with LS tasks. The sensation and interpretation of a person`s own body and movements is a source of spatial information and may affect spatial ability and performance (Hegarty et al., 2006). This is an important difference between SS and LS tasks and it seems that VR tasks should not be categorized as a LS task. For this reason the present study does not include VR tasks and they will not be further described.

A LS task will contain much more information compared to a SS test. Beyond the participant`s own body, there are several possible information levels that can be utilized when facing a spatial challenge. The need for classifying stimuli as relevant or irrelevant to the task is suddenly an issue. The demand on attentional focus will increase depending on the complexity of the surroundings. While SS tasks are carried out in short time intervals, LS tasks often extend over longer periods of time and spatial knowledge may be necessary to acquire during days or even months. This emphasizes the necessity for long term memory in addition to the already described processes of WM (Hegarty & Waller, 2004). Along with visuospatial information LS situations offer the possible use of other senses. Smelling, hearing and tactile stimuli can contribute to the total spatial experience.

The factor structure of LS spatial abilities is yet to be described. In fact, the extent to which LS spatial abilities overlap with SS spatial abilities is still being debated. In addition, neuropsychological studies have shown that different brain structures and processes are involved depending on the scale of space characterizing the spatial information that is processed (Hegarty et al.,2006). This could indicate that the abilities differ in important ways.

Different models for the relationship between the two abilities have been proposed. Hegarty et al. (2006) concluded that spatial abilities at different scales of space are just partially associated. Three important abilities are shared: The ability to encode spatial information from visual stimuli, the ability to hold and manipulate representations in working memory, and the ability to draw inferences from spatial representations. The same study also reports an additional LS ability as the skill to utilize the motion of the body for updating and spatial learning (Hegarty et al.,2006).

Studies have demonstrated that LS performance can only partly be predicted by performance in SS tests (e.g. Kozhevnikov et al., 2006). The single best predictive factor for spatial learning in LS navigation tasks was found to be the individual`s own rating of sense of orientation. Investigations of the relationship between object-based spatial abilities like spatial visualization and mental rotation have produced mixed results: If any relationship between abilities of SS and LS has been found, it has been weak and moderate at the best (Kozhevnikov ey al., 2006). Malinowski (2001) demonstrated that a test of mental rotation could predict male performance on an orientation task. The female picture turned out to be more complicated as a number of the females who performed poorly on the mental rotation test still did an excellent job on the LS orientation task.

Spatial competence would be defined as the sum of several spatial abilities. A LS task has the potential of revealing all the abilities shared with a SS test and the additional aspects which are unique for LS abilities. This may be the nearest we come to a full picture of spatial competence. In other words, a research perspective aiming at defining different strategies used to solve a particular task will benefit from a large scale approach.

Individual differences

Spatial abilities can be studied from a differential research perspective. Huge differences in spatial performance are clearly established in several studies (e.g Lawton, 1996; Hegarty et al., 2006). Both systematical and apparently non-systematical differences emerge from the data. Variables like age and gender can account for some of the variations in performance, and much effort has been put into understanding the nature of these systematic differences. Still, a large proportion of the variations we observe cannot be fully explained by these variables alone. The remaining differences in performance can probably best be understood by going one step back, trying to detect the additional variables that play a role in determining individual differences.

In the quest for the underlying reasons for individual differences several stones have been turned: Investigators have explored variables like experience, handedness or hormones, to mention some. Common for these are the possible involvement of *hemispheric lateralization*. For practical reasons, the *effects* of lateralization are often studied rather than the lateralization per se. Individual differences in spatial performance due to variations in lateralization can give way to different strategies for solving the same spatial task. By exploring different strategies we can see signs of hemispheric strength, preferences or specializations within the individuals (Kolb & Whishaw, 2003).

While explanations in terms of gender/hormones, age, or sex roles and experiences have been focused as separate explanations of spatial performance differences, others have underlined the interaction between them all. The “bent twig”- theory proposed by Sherman (1978) illustrates how biological and environmental factors can be part of one and the same explanation. The approach is based on the old saying: “As the twig is bent, so grows the tree”. Sherman argued that our predisposition for certain abilities is involved when choosing among different activities. This results in plenty of experience in activities that we already have an innate advantage for. It can be added that the circle would be complete when even social factors like sex role expectations further stress a possible innate gender difference. A strong specialization for different activities would be the result. It is reasonable to assume that this influences a person’s angle of attack when presented with several problems, including spatial tasks. When exploring the spatial abilities of an individual one should allow every possibility to solve the spatial challenges in an individual way. Later evaluations will then reveal the strengths and weaknesses of each strategy in relation to the given task.

Studies investigating the use of different strategies can contribute to the understanding of the cognitive processes involved in spatial abilities. Comparing the spatial performance with measures of other cognitive abilities enables us to discover which cognitive processes that influence spatial abilities the most.

Spatial abilities and performance can also be studied as a result of the limitations of different cognitive processes. The limited capacity of working memory would be relevant for this approach.

Strategies

The concept of strategies has often served as a life-boat or scapegoat; whenever there is a "how" we can't answer for, we call it a strategy. In explaining individual differences in spatial abilities the spatial strategy is a solution. A spatial strategy can be defined by the spatial information upon which we base our approach to a challenge.

It has been found that individuals are selectively paying attention to different aspects of the environmental information at hand (Bosco et al., 2004). This individual attentional focus results in individual forms of spatial knowledge upon which the spatial performance depends (Pazzaglia & De Beni, 2001).

Several distinctions have been made in an effort to categorize spatial cues or information that might be useful in solving a spatial task. It seems necessary to stress the fact that the concept of strategies, almost without exceptions, refers to the different ways to use available information in a LS task.

It has been proposed that an individual can solve the spatial challenge based on an understanding of the spatial relations in an environment, also called *configuration knowledge*, or based on *knowledge of places and the routes that connect them* (Evans, 1980). The theory does not state how this information is acquired, but a distinction between survey and route representations is claimed to follow from the different understandings of the spatial layout. Neuropsychological evidence confirms that spatial (mental) representations take the form of cognitive maps (Kolb & Whishaw, 2003).

According to Siegel and White (1975), the development of cognitive maps is divided in three stages. Once becoming familiar with an environment, a set of reference points, or *landmarks*, will stand out. Next, the representation of the *routes* that connects these and the actions needed to link the reference points (eg: turn left) can emerge. Finally the development of survey representations enables us to create a map-like image of the spatial information at hand. The description of spatial ability as developing through phases seems to fit well with findings of spatial abilities improving in children with age, matureness and experience (Hegarty & Waller, 2005). This theory also states that there will be individual differences in the utilization of these cognitive maps -if a successful development has taken place at all.

It is well established that spatial performance depends upon the mental representations available. In fact, many researchers agree that the mental representations give rise to at least two different strategies employed in spatial problem solving: The orientation strategy and the route strategy (Lawton, 1996). Other studies name strategies differently: survey and landmark are also referring to the kind of information focused by the individual. The different strategies have demonstrated their efficiency in way-finding tasks. Successful navigation can take place even when individuals have poor configurational understanding of the environment (Denis, Pazzaglia, Cornoldi & Bertolo, 1999). In a study conducted by Thorndyke and Hayes-Roth (cited in Bosco et al., 2004) spatial performance differences of another kind was found. In estimating route distance between landmarks, navigating in the environment gave the most accurate estimation. On the other hand, the best judgment of air distance was shown when individuals acquired map information.

Neuropsychologists offer another approach to the understanding of different strategies. Two separate systems for spatial navigation seem to affect spatial performance: While one system is utilizing *allocentric cues*; information from the surroundings, another is based on a fundamental human (and nonhuman) skill called dead reckoning (Kolb & Whishaw, 2003). This is an ability to deduce information from movements of the body in order to measure or estimate spatial properties like speed and direction. Dead reckoning is a primitive form of navigation useful not only to animals, but in the general lack of mechanical ways of measuring speed, time and direction. Cues from movements of the body, called *idiothetic (egocentric) cues*, or from the sensory system provide the necessary information to monitor travelling distance, relation to a starting point, speed and travelling time. The wind resistance, optical flow, sounds and odors are examples of idiothetic information. Monitoring own movements and copying those in a reverse order would also serve as a way to get back to the starting point. This contribution to the understanding of spatial ability emphasizes the importance of active processes. In a study by Bosco et al (2004), gender differences indicated that an active process is more critical to women than to men in the execution of orientation tasks. The ability to update spatial information and reorientation was found to be an accurate predictor for women's LS abilities. Men tended to rely on visuospatial abilities in an orientation task to a greater extent than women and their visuospatial WM performance seemed to predict their orientation performance. The investigators conclude that cognitive strategies can modulate cognitive abilities. The spatial performance of individuals, as well as gender, can be interpreted as a result of both cognitive abilities and strategy use.

Different strategies may have different advantages, even if both get you successfully from one place to another. How individuals can use different information and still navigate successfully in the same environment is an interesting question assumed to be enlightened by this study.

This study and hypotheses

We evaluated performance on paper and pen tests from a relatively large group of students, and went on to focus on those participants who had the most different abilities. These extreme individuals' performances in an indoor navigation task were compared as were their decoding abilities. In order to create a task that would allow participants to use different strategies we set up an indoor navigating route with several additional tasks that would require the use of both environmental information and idiothetic cues. A full description is offered under the methods section of the applied performance phase.

There is no consensus on the predictive value of SS tests for LS performance. Given the large variations in performance both on SS tests and on LS tasks, important information may hide in the data if not the same individuals are tested in both situations. By focusing on those individuals with the most diverging performance and using a within-subjects design an existing pattern would become clearer.

A wide range of individual performances was expected to result from the ability screening phase. The individual's results in the computerized mental rotations test were expected to be highly correlated to the same individual's performances on the equivalent paper-and pen test. Three hypotheses initiated this two steps study: 1. High spatial performance in the large scale test is based on selective decoding. 2. Individuals showing high spatial performance are more able to ignore irrelevant information. 3. Individuals showing poor spatial performance are more reliant on unselective decoding (Repovŝ & Baddeley, 2006).

Ability screening phase

Method

Participants. This initial phase of the study included 256 students (89 males and 167 females) from the University of Tromsø. They were recruited from several different study areas (44.5% medicine, 30.1% psychology, 12.1% law, 12.9% others). All participants gave their informed consent. Twenty-five of the participants were drawn randomly and rewarded with a gift check of 100 NOK.

Materials. The participants completed a form which indicated their sex, study area, and rating of their own sense of orientation as good or less good. The participants also reported which primary school they had attended to make sure that the surroundings of the next phase of the study would be novel to the participants. Contact information was gathered for recruiting purposes to the next phase of this study. This information was kept separate; locked away from the test results and later destroyed, according to the directions of NSD (Norwegian Social Science Data Services).

Individual differences in spatial ability were assessed by the use of three internationally established tests. *The Paper Folding Test* (PFT; Ekstrom et al., 1976) is a two dimensional spatial task. A target object is presented and illustrates a sheet of paper which is folded and then pierced. Five alternatives are then presented, allowing the participant to decide which unfolded sheet of paper that is equivalent to the target object. Only one of the alternatives is correct and the participant is supposed to mark the correct answer with an x.

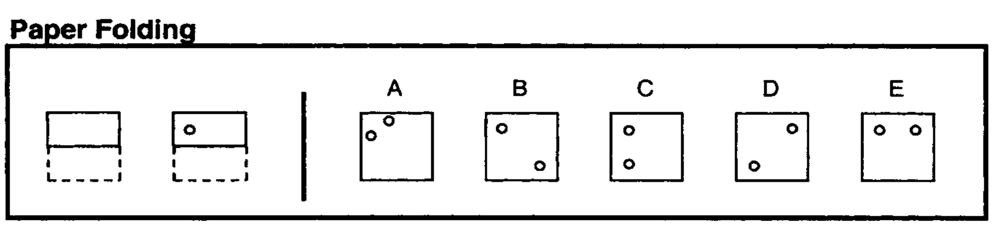

Figure 1. The Paper Folding Test requires mental manipulations in serial operations. The ability of spatial visualization is isolated as an essential factor of spatial abilities.

The test consists of 20 different tasks. To correct for guessing; the total score is calculated by the number marked correctly minus a fraction of the number marked incorrectly:

Score = rights - (wrongs / n-1)

Where n is the number of alternatives, here; 5. The maximum score for this test is 20 points.

The Card Rotations Test (CRT; Ekstrom et al., 1976) consists of 20 target figures or cards. Each card is presented followed by 8 alternative illustrations of the figure. The alternatives are rotated two-dimensionally, and mirrored versions of the target figure can also be presented a number of times among the alternatives. As long as the target figure is just rotated and not mirrored, this alternative is to be marked as "the same" with an x in the "s"-box. When the alternative is a mirrored version of the target figure the participant should mark this as "different" by making an x in the "d"-box.

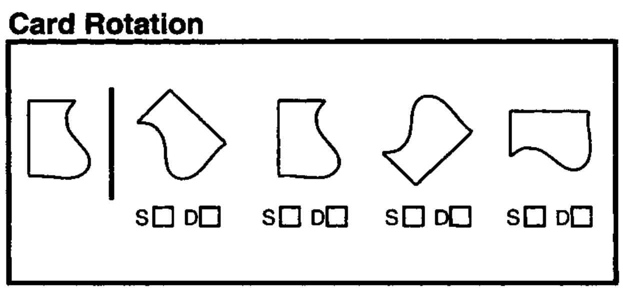

Figure 2. The Card Rotation Test gauges the ability to mentally rotate the configuration. Factor analytic researchers value this test for its demands on abilities like spatial orientation and perceptual speed.

The total score on this test will be the number of boxes with correct answers minus the boxes with wrong answers, making it a disadvantage to guess. The maximum score for this test is 160 points.

The Vandenberg and Kuse Mental Rotations Test (VK-MRT; Vandenberg & Kuse, 1978) is a paper and pen version with the Shepard and Metzler (1971) mental rotation objects. The test used in this study is a revised and redrawn version of the original (Peters et al., 1995). Twenty-four target figures illustrating a three dimensional object are to be compared with rotated version of the same or different objects. A task consists of a target figure, two correct alternatives and two incorrect alternatives.

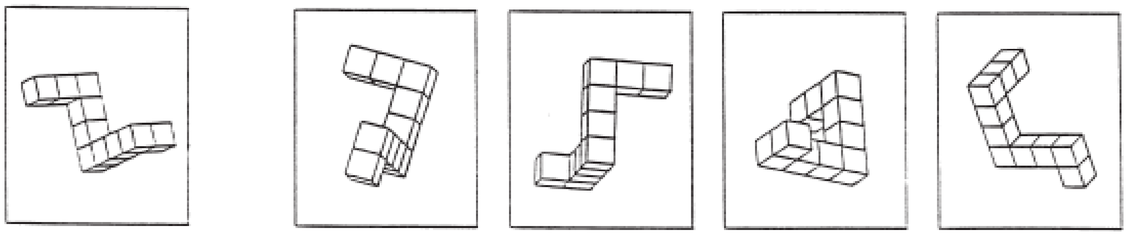

Figure 3. The Vandenberg and Kuse Mental Rotations Test. The target figure is presented on the left. The four alternatives include two figures that are identical to the target in structure, but shown in various rotations. The test requires the ability to mentally rotate a three dimensional object.

Participants get credit only by indicating both the identical objects. To correct for guessing the total scores are unaffected by incomplete answers; only one correct choice selected, one correct and the other incorrect or both incorrect. The maximum score for this test is 24 points.

Procedure. The tests were administered to groups varying from about 10-40 participants in 45-minutes sessions. The experimenter introduced each test followed by a period of time for the participants to read the instruction on the cover page of the test and study the examples. The three tests were attached together and colored sheets of paper separated the pages of each test. To ensure that everyone was exposed to the test for a precise amount of time, the experimenter dictated the turning of each page and used a stop watch to control the time for each page. While both the PFT and the CRT operates with 3 minutes a page, the VK-MRT allows 3 and alternatively 4 minutes for two pages. In this study the limit of 3 minutes was chosen. The sequence of presentation was the same for all the participants; the individual questionnaire was followed by the PFT, the CRT and at last the VK-MRT. Questions were answered afterwards and participants were informed about the possibilities of being part of a follow-up study with a full debriefing.

Results

The individual differences were confirmed to be large. The maximum score of all three tests was 204. The mean total score (all three tests) for all participants (n=256) was 117.36 (SD=39.33) with a range from 7.25 to 197.75. For men (n=89) the mean total score was 127.92 (SD=40.27) and for women (n=167) the mean total score was 112.11 (SD=37.54). This difference was significant, F(1,254)=10.20; p=.002.

Mean scores for each test of the ability screening phase are given in Table 1. To test for gender differences oneway ANOVAs were used. On the CRT, men (M=104.57) performed better than women (M=91.66). This difference was significant, F(1,254)=9.00; p=.003. A significant gender difference was also found on the VK-MRT where the mean scores for men and women were 13.40 and 9.59 respectively, F (1,254) = 37.59; p < .005.

Table 1. Mean score on the PFT, CRT, VK-MRT and total score according to gender.

	PFT		CRT		VK-MRT		Total score		
Gender	M	SD	M	SD	M	SD	M	SD	N
Men	10.46	4.61	104.57^a	34.18	13.40^b	4.91	127.92^c	40.27	89
Women	10.55	4.05	91.66^a	32.06	9.59^b	4.56	111.73^c	37.74	167
Total	10.52	4.25	96.15	33.32	10.91	5.02	117.36	39.33	256

Note: The letters ^{a,b,c} denote significantly different gender means (p<.005).

Discussion

The main aim of this first phase of the study was to group the participants according to their SS performance. The tests were chosen on the basis of their different qualities; visualization (PFT), spatial orientation (CRT), and three-dimensional mental rotation (VK-MRT) are all factors assumed to be part of fundamental spatial abilities (Malinowski, 2001). In the screening study it was a goal to explore as many of the traditional spatial factors as possible in a reasonable amount of time. The sessions of 45-minutes appeared to be just about the limit to the participants; -the test situations found place in the prolonging of a lecture. Performance on these tests depends on concentration and some of the students gave the impression of being tired. On the other hand; this situation was the same for all the participants.

The task of mental rotation has been found to favor men in a number of studies (e.g. Linn & Peterson, 1985). In line with these findings, the only significant gender difference in the present study was on the three dimensional rotations task. The other variations seem unaccounted for. It is plausible to conclude that the individuals scoring high on these three tests have a) the spatial abilities that are required and b) all the information they need to solve the problem. But for the individuals not able to solve these tests the picture is not as clear; they could lack the fundamental abilities and/or they could be in short of useful information. A small scale test offers less information compared to a large scale test situation thus limiting alternative strategies. As mentioned earlier, individuals tend to rely on different information in solving LS tasks.

Applied performance phase

Method

Participants. Forty-eight students (20 male, 28 female) with a mean age of 23.27 years (SD 7.02) (41.7% from medicine, 27% from psychology, 12.5% from law, 18.8% others) were recruited from the ability screening phase. The aim was to recruit about 50 students from the 10% best and 10% poorest performers of the ability screening phase. However several students were not willing or able to participate. It appeared to be more difficult to recruit the poorest performers. Therefore this second phase included 23 participants (15 male, 8 female) among the 12% of the best performers and 25 participants (12 male, 13 female) among the 22% of the poorest performers. All individuals in the best performers group had scores above 160 and all in the poorest group had scores below 90. Mean score was 52.86 (SD=26.23) and 178.09 (SD=12.15) in the two groups respectively. Students that had any familiarity with the surroundings being used for the orientation task were excluded. All participants gave their informed consent and received a voucher for coffee and a muffin at the university campus.

Materials. A computerized mental rotation test (MRT; Wiking & Østmo, 2008) was used to confirm the results from the VK-MRT. The test was presented on an Acer Aspire Notepad 5613ZWLMi computer with 15.4” LCD screen. The screen resolution was 1280 x 768 pixels. The test was constructed with the stimuli from the original Shepard and Metzler mental rotations test (1971). Their original images are combined into 100 unique pairs, half showing the same object and half the object together with its mirrored reversed version. The five different objects presented differed in degree of in-depth rotation; from 0 to 180 degrees in 20 degrees increment. This results in 10 different rotation distances for each of the five object types in both the similar and different pairs. The mental rotation test was programmed in the E-prime software version 1.1 SP3 (Schneider, Eschman & Zuccolotto, 2002). The objects were presented side by side in the center of the screen. Each pair was 906x456 pixels large. Five practice trials with feedback were followed by 100 test trials with no feedback. A fixation cross was presented for 1000 ms before each trial. The stimuli remained on the screen until the participant responded or for a maximum 10 seconds. The task is to decide whether the two figures are the same or different and respond both quickly and accurately by pressing two keys on the computer. The order of the presentation of stimuli was randomized for each participant (Wiking & Østmo, 2008).

The (Stroop) Interference Test was presented on a HP Pavillion ze 2000 with 15" screen, and the screen resolution was set at 1280x1024 pixels. The program presented a fixation mark for 1000 ms followed by one of four color-names. The letters of the word could be presented in any one of these colors; 40 trials presented the meaning of the word in the same color as the letters (1x4x10). In 120 trials the meaning of the word differed from the color it was written in (3x4x10). The word only stayed on the screen for 1500ms. The task was to decide which color that appeared on the screen and not which word. The participant was supposed to respond quickly by using one of four different keys on the computer. In this study we also presented 80 trials consisting of the four different compass directions (NSEW) (4x4x5). The test then had a total of 240 trials which were presented in a random order.

The orientation task was original for this study and measured way-finding skills and the ability to focus on relevant information on the way through an unfamiliar building. Participants studied a route on a map of the 2 flours of the building for 2 minutes. The orientation task was performed in solitude and the time was measured with a stop watch. The location was a primary school in Tromsø, and the study was carried out when the school was empty. However, the building was still packed with distractors: Posters, banners, lively colors, books, furniture,textiles, toys, tools and equipments dominated the field of sights. There were also windows to look out from, symmetry of rooms, geometric proportions and logically placed locations (eg. toilets, wardrobes, emergency exits and so on).

The experimenter measured the time used on the route from the participant left the site of instructions till he/she was back. Maximum time available on the route was 30 minutes.

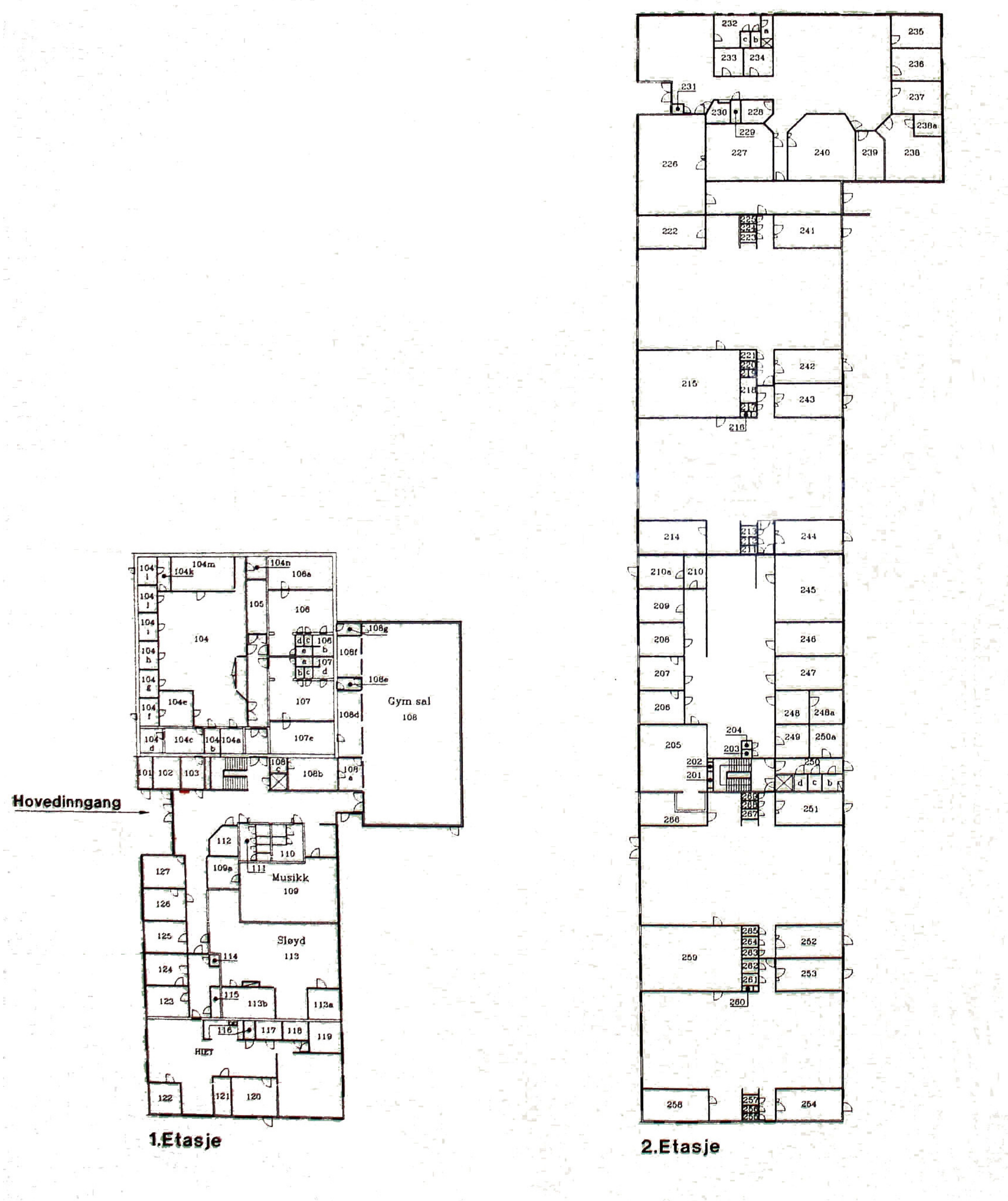

Figure 4. The map of the building shows the two floors and was presented to the participants with marked routes for navigation through the indoor landscape.

Along the route the experimenter had placed additional tasks to be solved and objects to be found. On the ground floor the participant would look for gold medals of chocolate hung in a characteristic ribbon. The number was not known by the participant who was told to gather medals along the memorized route. Actually there were 6 medals along the route, but the experimenter had placed 3 additional “false” medals in other strategic rooms. If returning with some of these, it would be obvious where the participant deviated from the correct route. One of the rooms at the end of the route of the ground floor had no windows. This room contained a task where the participant would indicate compass directions. The four directions were displayed by notepads fixed on the floor, but the participant would decide which were north, south, east and west. For indicating correct directions one point was given. For just 90° wrong but still reciprocity, half a point was gained.

On the first floor participants would look for and collect 6 pairs of objects/trophies with the same characteristic ribbon attached. The 12 trophies were toy figures of about 10 cm height. The two figures of each pair (copies) were placed in mirrored locations. The participant was only told that the trophies were to be found in corresponding places. The first floor of the building is mirrored apart from one section of library and offices, and one section at the west end that we did not access. This floor also contained additional tasks: In the library there was a poster on the floor with an adjustable arrow. The participant should indicate the direction of the entrance of the building, where he/she had arrived previously. Within 15° deviation each way, the participant could obtain one point from this task. Two more poster-tasks with arrows were placed in mirrored rooms, -one for deciding east and one for deciding north. An indication showing from 0°-50° deviation, deserved 1 point. For a deviation up to 90° the participant would obtain half a point. In addition to all the excess information already present, a fruit-plate was placed on a coffee-table in the library next to the poster task. On one of the blackboards the out-of-seasons greeting “GOD JUL” (Merry Christmas) was written.

A follow-up interview was completed after the orientation task. Here the participant would account for the knowledge of the fruit-plate, what kind of fruit it consisted of, the greeting on the blackboard, the emergency exits of first floor, which room that would be above one specific room of the ground floor and last; how the systematical placing of the 12 trophies could be characterized. By recognizing the mirrored placing the participant would be granted one point. A total of 5 points could be obtained. By using the map without the route the participant should redraw the route he/she had followed and try to place the sinks in the classrooms. Finally the participant was asked to estimate the length and width of the building.

Procedure. As the participants were recruited, they were scheduled for an exclusive appointment, usually with one hour between each participant. They did not receive information about the nature of the tests at this point. At arrival, the participants were greeted and briefly introduced to the computerized tests and told of the following orientation task. They completed the MRT first and the Stroop interference test next. They then received instructions for the orientation task (see Appendix) and completed the route. Participants that did not return within 30 minutes were restrained from continuing. The follow-up interview was conducted and a full debriefing was offered. The whole session lasted for about 45 minutes. After each participant, the experimenter tracked the route and gathered information from posters, replaced the medals and the trophies.

Data-coding and analysis. On the computerized MRT and Stroop interference tests the results were analyzed in terms of both time and accuracy. The means of the individual response times were calculated for correct responses only. Response times that were more than three standard deviations from the individual mean were removed from the data files.

The data from the orientation task was sorted; variables involving holistic information from the route were summarized. The three poster-tasks of deciding compass directions, the point-to-the-entrance task, recognition of the mirrored placing of trophies and knowledge of the corresponding rooms across the floors were grouped and labeled A-variables. The maximum score for this holistic knowledge was 6 points (see materials section). Variables involving piecemeal information were also summarized. The same maximum score could be obtained if the participant could account for the existence, the whereabouts and the contents of the fruit-plate, the greeting on the blackboard, the emergency exits and the placing of the sinks. These B-variables were assumed to exemplify piecemeal knowledge.

Results

As expected the results from the computerized MRT correlated with the results from the VK-MRT: $r = .83$; $p < .001$. On the VK-MRT the mean score for women (n=28) was 9.14, for men (n=20) it was 15.45. The difference was significant: $F(1,46) = 12.83$; $p < .001$. For the computerized MRT the means were .75 for females and .84 for men, the difference was however not significant, $F(1,46) = 3.68$; $p < .061$.

On the computerized MRT, the low performance group from the screening phase had a mean accuracy of .70 (SD=.11), and the high performance group had a mean accuracy of .91 (SD=.05). A one-way ANOVA confirmed that these extreme groups were also significantly different on the MRT, $F(1,46) = 76.92$; $p<.001$.

One aim of the applied phase of the study was to determine if the individual orientation strategies differed significantly. Time efficiency was estimated by dividing the time used on the route with the number of items found and tasks solved. Depending on the scores of A- and B-variables, the participants were categorized. The mean score for the participants on A-variables was 2.65. The mean score for the participants for B-variables was 2.31. By categorizing the individuals as either high or low compared to the mean, four groups were described: Low A and B (ab), low A and high B (aB), high A and low B (Ab), high A and B (AB). The combinations were assumed to illustrate different strategies. The analyses show that the aB group was significantly less time efficient compared to all the other groups, $F(3,44)=4.53$; $p=.007$. Group AB had a better accuracy on the Stroop interference test compared to both aB and ab, but the overall difference between the groups was not significant, $F(3,44)=2.66$; $p=.06$. The results are shown in Table 2. The scores on the A-variables stand out as critical to both time efficiency on the route and accuracy on the Stroop interference test. Accuracy on the mental rotation test was not found to be significantly different among the four groups, $F(3,44)=1.78$; $p=.165$.

Table 2. Combinations of spatial strategies and mean scores on time efficiency on the route, the Stroop accuracy and MRT accuracy.

	Time efficiency		Total solved		Stroop ACC		MRT ACC		
Strategy group	M	SD	M	SD	M	SD	M	SD	N
Low A and B	1.47[b]	.60	2.20[b]	1.42	.87	.15	.77	.15	15
Low A, high B	2.21[a]	.87	1.00[c]	.93	.82[b]	.18	.74	.15	8
High A, low B	1.26[b]	.45	3.67[a]	.89	.93	.06	.86	.12	12
High A and B	1.51[b]	.44	3.69[a]	.48	.95[a]	.02	.81	.11	13

Note: Mean scores with different letters [a,b,c] are significantly different (Tukey HSD, $p<.05$).

By focusing on the scores of holistic information alone (A-variables), two larger groups were then analysed; low A and high A. As shown in table 3; significant differences were found in mean score on each SS test and on total score of the ability screening phase. Individuals showing a high score for holistic strategy (high A) were significantly outperforming individuals with low scores on this strategy, $F(1,46)=6.83$; $p=.012$.

Table 3. The mean scores and total on the SS tests for participants falling in the low A and high A groups on the LS task.

	PFT		CRT		VK-MRT		Total score		
Strategy group	M	SD	M	SD	M	SD	M	SD	N
Low A	8.82[a]	5.61	70.09[b]	52.11	9.30[c]	6.57	88.21[d]	63.16	23
High A	12.19[a]	5.18	109.32[b]	53.63	14.04[c]	6.16	135.55[d]	62.24	25

Note: Strategy groups are significantly different at [a] $p=.035$, [b] $p=.014$, [c] $p=.013$, and [d] $p=.012$.

On the computerized MRT, the low A group had a mean accuracy of .76 (SD=.15) and the high A group had a mean accuracy of .84 (SD=.12). A one-way ANOVA showed that these strategy groups were significantly different on the MRT, $F(1,46)=4.47$; $p=.04$.

Discussion

The highly significant difference between the groups on the computerized MRT verified that the participants who had been recruited for his second phase of the study were in fact those extreme individuals that we wanted to test further.

The coding of data from the orientation route into A- and B-variables was done according to the characteristic differences of knowledge derived from different kind of information. A-variables involve survey information; compass directions and the recognition of spatial layout from a bird's perspective depend on a holistic view of the surroundings. Piecemeal information along the route; the fruit-plate, the greeting on the blackboard, and so on, provides scarce information for the orientation task itself. Nevertheless: Participants picked up this information as well, -to different extents.

The decoding abilities measured by the Stroop Interference test revealed that the individuals with a high score of holistic strategy tended to use selected decoding to a larger extent than the low score individuals.

The decision that the participant should perform the orientation task on their own, removes the possibility that participants could behave differently in the company of others. Still it opens for other biases: We were not able to control if the persons turned and did parts of the route several times. Some participants seamed more eager than others to find the trophies. The problems of finding the objects along the route would be revealed by the estimated variable "time efficiency".

General Discussion

The idea that individuals differ in the way they focus spatial attention (e.g Repovŝ & Baddeley, 2006) is confirmed in this present study. The ability to lay stress on different information or stimuli gives rise to two strategies which differ significantly in important ways. The orientation task of this study promoted the use of a holistic spatial strategy: The map provided a survey perspective of the surroundings and the participants were hinted that the trophies were to be found according to a system. The four compass tasks along the route benefited from the use of global reference systems (abstract Euclidian navigation). Despite the advantages of a holistic spatial strategy, many of the participants focused on detail information in the environment, -either additional (AB) or alternatively (aB). This provides piecemeal knowledge that seems irrelevant for the orientation task itself: In order to navigate in an unfamiliar environment, it is not useful to notice the greeting on the blackboard or the fruit-plate, -the only relevance these offer are as landmarks. In a study by Dabbs et al. (1997) connections between different spatial abilities and navigation strategies are drawn:

“(…)it is plausible that object location memory promotes the use of landmarks in navigation, whereas three-dimensional visualization promotes the use of abstract Euclidian navigation.” (Dabbs et al.,1997, p. 90).

In this study the decoding abilities of the individuals were put to test. The differences found between the individuals with respects to both their SS performance and their use of strategy in the LS task, justify this focus. The significant difference for strategy A on all the SS tests in the ability screening phase confirms that these tests measure the ability to focus on relevant information; the ability of selective decoding. According to the hypotheses the decoding abilities may lead to different strategies. The least able individuals on the SS tests are reliant on unselective decoding. Individuals gaining a high score benefit from the abstraction of useful information as well from their spatial abilities. It is a matter of definitions whether the selective/unselective decoding is part of the special abilities associated with the visuospatial sketchpad or a matter of other cognitive abilities. It could be argued that the decoding process is limited by the attentional capacity of the central executive (Repovs & Baddeley, 2006). These authors suggest however that an attentional mechanism for maintenance of features and objects in visual WM is involved in selecting perceptual objects in a visual scene. They conclude that the central executive is mostly involved as a source of attentional control in complex cognitive tasks, and that the visuospatial sketchpad is supporting this by guiding visual and spatial attention. It seems that this attentional control and decoding process could be a matter of cooperation between these two components of the WM. Decoding abilities are perhaps not best defined as a spatial ability alone but rather as a factor of spatial competence.

The Partial Dissociation Model earlier referred to (Hegarty et al., 2006) describes how spatial abilities are somehow overlapping for SS- and LS abilities: the ability to encode spatial information from visual stimuli, the ability to hold and manipulate representations in WM, and the ability to draw interferences from spatial representations. The model could in fact been called partly unitary; shared abilities could implicate connections between performance at different scales. Earlier research of the connections between abilities like mental rotation and spatial visualization measured by a navigation task has not provided evidence for a strong relationship (Kozhevnikov et al., 2006).

In contrast, our findings support a strong connection between performances on the two scales. Participants with high score the SS tests: spatial visualization, spatial orientation and three-dimensional rotations, are also users of a holistic navigation strategy that include abstract

Euclidian navigation. If measures of spatial abilities at different scales are correlated it does not necessarily mean that they are based on the same capacities or processes. The SS task and the LS task may depend on different spatial abilities and still be good predictors of each other. It is however important to remember the possibility that the two tasks might be influenced by a third factor like genetics, experience or attentional control.

The body of research about the connections between basic spatial abilities like they are explored in the SS tests and the LS spatial performance has been scarce. This study has shown that abilities relevant for SS situations are also relevant to situations of LS navigation.

Previous studies have emphasized mental rotation abilities as the SS ability mostly involved in determining strategies (Malinowski, 2001). Pazzaglia et al. (2001) confirmed these findings in their study: High-survey individuals outperformed landmark-centered individuals on the MRT. In accordance to the present study they concluded that the two groups of individuals adopt different strategies in processing spatial information, pointing to the characteristics of the MRT and suggesting that high-survey participants were more able to adopt a spatial holistic strategy in performing psychometric spatial tasks. Our study does not conclude if the holistic spatial strategy seen in the navigation task is influencing the abilities to solve the MRT, or if the abilities required solving the MRT is influencing the strategy use in the navigation task. Instead we pinpoint a third factor; attentional control, which seems to influence the spatial performances on both the different scales.

In the present study spatial visualization and spatial orientation also played a role in the use of strategies. It would have been favorable to explore even more factors in the screening of abilities. Spatial perception is a factor that could have been included. The ability to sense horizontality and verticality in a SS test would have been interesting to compare with the ability to use other global reference systems, e.g. compass directions.

In the applied performance phase of this study one of the compass direction tasks were placed in a room without any windows or outdoor references. The participants had actually nearly completed the route of the ground floor before entering this room. The question is how the individuals were able to decide compass directions in this room without the use of idiothetic cues. As described, by deducing information from the body's movements, being able to recall the route by imagining the actions in reverse order, dead reckoning is a source of spatial information. There is face validity to the idea that dead reckoning would be likely to relate to special perception as a SS measured factor.

Piecemeal information as well as object location memory share some similarities with landmarks (Dabbs et al.,1998). As pointed out by Siegel and White (1975), the representation of isolated landmarks is the first step in developing representations of complex spatial environments. This first level includes isolated landmarks without the routes that connect them. These representations are necessary in order to acquire the route representations. The survey representations are general and more complex, but both these two latter steps of the development have proved to serve as navigation strategies (Pazzaglia & De Beni, 2001). In this study we closed focus on the most extreme individuals in the distribution. The poor performers were way under average and it is tempting to suggest that these individuals relied on landmarks alone as an orientation strategy. As pointed out by Siegel and White (1975), landmarks alone do not contain enough information to navigate by.

In everyday life, there might be unexpected limitations that influence our abilities and force us to use alternative strategies. In other cases, the limits will be our own; like the individual limitations of the executive functions for selective decoding. The focus on details could provide useful information in real life. An orientation task, e.g. sightseeing in an unfamiliar city, often involves more than finding back to the hotel. Diverse information gathered on the way might turn out useful in the long run. Knowing where to find a pharmacy, a cheap restaurant, toilets or emergency exits will be most appreciated when the need is urgent!

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Appendix

Forespørsel om å delta i forskningsprosjekt.

Målet med prosjektet er å undersøke individuelle forskjeller i bruk av informasjon om romlige forhold.

Du vil få gjennomføre tre internasjonalt etablerte tester. Testene vil bli presentert én av gangen og det er viktig at du følger instruksjonene. Hver test har en begrenset tidsramme som må overholdes. Instrukser vil bli gitt fortløpende.

Noen av deltakerne vil bli valgt ut og spurt om å være med i videre undersøkelser i løpet av noen uker. Du blir derfor bedt om å oppgi e-post adresse og et telefonnummer du kan nås på.

Deltakelse i forsøket er frivillig og du kan når som helst avbryte uten å gi en nærmere grunn.

De endelige testresultatene vil bli lagret anonymt slik at ikke den enkelte deltaker kan identifiseres.

Jeg har lest informasjonen og samtykker i å delta i dette prosjektet.

Dato/sted: Navn:

Henvendelser kan rettes til prosjektansvarlig førsteamanuensis Susanne Wiking på e-post wiking@psyk.uit.no eller testleder Anne-Karine Melsom på telefon 95732605 eller e-post aho030@mailbox.uit.no

Vennligst besvar alle punktene og stryk det som ikke passer:

Kjønn: Mann/kvinne

E-postadresse: ______________________________________

Telefon: ____________________________

Hvilket fag studerer du: __________________________

Hvilken barneskole har du gått på: _______________________________

Hva var favorittleken din i 6-12-års alderen: ________________________________

Hånddominans: Høyre-/venstrehendt

Vurdering av egen retningssans: god/mindre god

Forespørsel om å delta i forskningsprosjekt

Målet med oppfølgingsstudiet er å undersøke individuelle forskjeller i bruk av romlig informasjon i flere typer oppgaver

Du vil få gjennomføre to tester på datamaskin og en praktisk oppgave. Du vil få instrukser før hver enkelt oppgave og det er viktig at disse følges.

Testingen avsluttes med en oppfølgingssamtale med forsøksleder.

Deltakelse i forsøket er frivillig og du kan når som helst avbryte uten å gi en nærmere grunn.

Testresultatene vil bli lagret anonymt slik at den enkelte deltaker ikke kan identifiseres.

Jeg har lest informasjonen og samtykker i å delta i dette prosjektet.

Dato/sted: Navn:

Instruks for navigasjon

1. Du vil få gjennomføre en innendørs sti-finner/orienteringsoppgave.

2. Du får nå studere dette kartet over skolebygningens to etasjer i 2 minutter. Du skal etterpå prøve å følge den løypa som er avmerket på kartet, og da uten kartet tilgjengelig.

3. Viser kartet. Tar tiden.

4. Så det greit ut?

5. Her i 1 etg. skal du plukke med deg flere sjokolade-gull-medaljer som henger i karakteristiske bånd. Samle sammen de du finner langs løypa og ta disse med deg.

6. Når du kommer opp trappa til 2. Etg. kan du selv velge om du vil starte til høyre eller venstre. I 2. Etg. skal du finne 6 trofè-par. Det er figurer som det er to-og-to av som henger i de samme vakre båndene som gull-medaljene i 1. Etg. Trofèene er plassert på steder som tilsvarer hverandre i etasjen. Det betyr at når du finner ett trofè på et bestemt sted, vil du finne det andre tvillingtrofèet på tilsvarende plass langs løpa på den andre siden av trappa. Du skal likevel følge løypa som på kartet og samle så mange trofèer du finner i den rekkefølgen som faller naturlig langs løypa.

7. Trofèene kan du holde eller legge i denne kurven.

8. Langs løypa er det også noen andre oppgaver du blir bedt om å løse. Disse er tydelig merket. Løs disse etter beste evne.

9. Jeg tar tiden på deg mens du utfører denne stifinner-testen. Max tid er 30 min.

10. Er oppdraget forstått?

11. Da skal du altså begynne her nede og samle medaljer langs løypa deretter gå opp og samle trofèer. Etter endt rute kommer du tilbake hit.

Lykke til!