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Individual differences in navigational strategy: implications for display design

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Three investigations that demonstrate the importance of considering individual differences when designing in-vehicle navigation systems are described. Drivers were categorised in terms of their spatial awareness and wayfinding strategies, based on brief self-report questionnaires. Experiment 1 revealed individual differences in route learning performance as a function of these categories and display modality (visual, auditory or both). Experiment 2 demonstrated that individuals within these categories use different route learning strategies that place differential demands on verbal vs. visuospatial working memory. Experiment 3 examined the navigational strategies and capabilities of older drivers and offers evidence-based design suggestions. These findings show that individual driver characteristics must be considered in order to reduce the attentional cost of extracting information from in-vehicle navigation systems. Effective displays are not a one size fits all configuration.

Keywords: navigation; spatial ability; route guidance systems; individual differences

1. Introduction

Navigating and learning novel routes are important everyday tasks, essential in many occupations (i.e. emergency response personnel, taxi cab drivers and bus drivers). The tasks are attentionally demanding and so can impact the performance of concurrent critical tasks such as driving. Geographic disorientation, or getting lost, increases the risk of crash involvement (Walker *et al*. 1990, Dingus *et al*. 1997, Burns 1999, Eby and Kostyniuk 1999). This, coupled with the huge toll that unnecessary driving places on ecological and economic resources, not to mention time wasted in traffic congestion (Burns 1999), underscores the importance of designing systems that effectively assist people with the navigation task.

Recent technological advances have led to the development of global positioning satellite based in-vehicle navigational and route guidance systems (RGS) that can assist people with the attentionally demanding task of navigation. However, despite their potential benefits, the impact of these systems on transportation safety is currently under debate (Noy 1997, Baldwin 2002, Harms and Patten 2003, Merat *et al*. 2005). Apart from design issues, driver characteristics represent an often-neglected factor that may influence the effectiveness of in-vehicle navigational devices.

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Large individual differences exist in both the strategies that individuals use when wayfinding and their performance in navigational tasks. Over half a century ago, Tolman (1948) observed that certain individuals (of the mice family) and nearly all individuals in certain circumstances have difficulty forming a large-scale cognitive map of an unfamiliar environment, resorting instead to a less effective narrow strip-like map. More recent research with humans (Lawton 1994, Lawton and Kallai 2002) indicates that this narrow strip-like map is likely to not be 'map-like' at all in humans, but rather consists of a sequential verbal list. The list contains items such as 'turn left in two blocks, turn right after three stoplights', etc. (Lawton 1994).

Sex, experience, age, navigational strategy and working memory ability are a few of the major individual factors consistently shown to account for significant amounts of variance in performance of navigational tasks (Lawton 1994, Baldwin 2002, Choi and Silverman 2003, Gugerty and Brooks 2004). Further, even when overt performance differences are not found, individuals may exhibit different patterns of brain activation (Hugdahl *et al*. 2006), indicative of the use of different processing approaches or strategies when navigating.

Variability among navigators suggests that different groups of individuals will benefit from or be adversely affected by different types of navigational aids and environmental distractions. For example, people who have great difficulty using maps or switching visual attention rapidly may benefit from auditory RGS (Baldwin 2002), whereas others may become agitated by not being provided with more global information that assists them with formation of a cognitive map of the area to be traversed (Baldwin and Reiss 2000).

This paper describes three investigations that each address the importance of considering individual differences in navigational strategies and abilities and how these differences may impact performance within the context of driving. Experiments 1 and 2 examined individual differences among young adults and Experiment 3 extended this research to adults over the age of 60 years. The first investigation examined the potential for individual differences in navigational ability to impact cognitive map construction as a function of the modality of the navigational aid. Before discussing this experiment, a general discussion of the types of differences typically observed is presented. A method of assessing these individual differences – which was used in each of the investigations to be discussed – is then presented.

2. Individual differences in navigational ability and strategy

Substantial individual differences in navigational ability have been observed (Choi and Silverman 2003, Kato and Takeuchi 2003). Males tend to excel in many navigational tasks (Cutmore *et al*. 2000, Saucier *et al*. 2003). Conversely, females tend to excel in tasks requiring memory for object locations (Choi and Silverman 2003, Choi and L'Hirondelle 2005). Navigational ability may, in turn, influence a person's preferred navigational strategy (Choi and Silverman 2003).

Individuals who report low proficiency using maps tend to utilise strategies that capitalise on verbal processing rather than visuospatial information (Streeter and Vitello 1986, Garden *et al*. 2002) and the reverse is true for persons who report high map proficiency. Strengthening this dichotomy, two navigational strategies, each relying primarily on different types of information, have been identified (Lawton 1994, 1996, 2001, Lawton and Kallai 2002). The first, referred to as a 'route' strategy, is characterised by the use of primarily sequential verbal information in the form of egocentric left and right 'turn by turn' instructions at particular streets or landmarks. The second strategy is referred to as an 'orientation' or 'survey' strategy. The survey strategy is characterised by construction of a cognitive map or spatial visualisation of the area that makes reference to cardinal directions and Euclidean distances between major landmarks that serve as reference anchors. Survey style navigators keep track of their direction of travel and tend to visualise a map of the area and where they are in relation to salient features, such as the centre of the city, as they traverse a particular course.

While differential use of these strategies is often reported between the sexes, differences between individuals as a function of how much navigational experience they have are also reported (Lawton and Kallai 2002). Additionally, people tend to use cardinal directions more as they age (Dabbs *et al.* 1998) and people in general who grow up in the Midwestern United States (where roads and streets are laid out in grid like patterns) report greater use of cardinal directions (Lawton 2001). Therefore, the relative use of these two different strategies appears to be based on experiential factors other than gender alone (Fields and Shelton 2006, Baldwin and Reagan in press). The current series of experiments focused on experiential factors and strategies and therefore attempts were made to control for the impact of possible sex differences by equating the numbers of males and females in experimental groups, but sex was explicitly examined.

Individuals who use survey strategies tend to have the additional advantage of having greater flexibility in navigational strategy. That is, they are better able to switch to a route strategy if situational demands extraneous to the navigation task place high demands on visuospatial resources (Saucier *et al.* 2003). Conversely, if route strategy navigators are prohibited from using verbal strategies (i.e. by imposing a concurrent articulatory suppression task), they are less able to switch strategies and therefore tend to exhibit greater performance decrements (Saucier *et al.* 2003). These differences in navigational ability and strategy are likely to influence the effectiveness of various RGS formats for individual users. This hypothesis was examined in the first experiment. Specifically, the study sought to determine if self-reported sense of direction (SOD) would impact individuals' use of navigational aids of different modalities. Self-reported SOD – defined by Kozlowski and Bryant (1977, p. 590) as 'people's estimation of their own spatial orientation ability' – has been used to predict other forms of spatial ability. Specifically, SOD is correlated with environmental spatial abilities such as pointing accuracy and rate of acquiring accurate mental representations of unfamiliar areas (Kozlowski and Bryant, 1977, Hegarty *et al.* 2002). Experiment 1 sought to determine if self-reported SOD was related to RGS usage.

3. Experiment 1

This study examined individual differences in cognitive map formation resulting from using a geo-centred or allocentric visual map route RGS vs. an ego-centred auditory RGS (Furukawa *et al.* 2004). First, two questionnaires, designed to assess navigational strategy and ability, were administered. The first, called the sense of direction questionnaire (SDQ), was developed by Takeuchi (1992): a short version (SDQ-S) has been validated in several samples of college students attending universities in Japan (Kato and Takeuchi 2003) and in the US (Carpenter *et al.* 2004). The SDQ-S consists of 17 statements pertaining to use of cardinal directions, formation of cognitive maps and use of landmarks. (Kato and Takeuchi (2003) provide a list of the specific items). Participants are asked to indicate on a scale of 1–5 how much they strongly agree – 1, or strongly disagree – 5 with each item.

So, for example, representative items include, 'I can make correct choices as to cardinal directions in an unfamiliar place' and 'I can't use landmarks in wayfinding'. A response of '1' would indicate that the respondent felt that statement strongly characterised him or her. Higher scores indicate less agreement and respondents can be classified into groups with either a good sense of direction (GSD) or a poor sense of direction (PSD).

The second questionnaire administered was Lawton's (1994) 'Wayfinding' strategies questionnaire. Items on this questionnaire are designed to distinguish between use of survey and route strategies. Survey strategies include use of cardinal directions and keeping track of the sun and moon and other similar items. Route strategies include counting the number of streets that are passed and asking for directions in terms of when to turn left or right at particular landmarks and other similar items (see Lawton (1994) for a complete list of all 14 items). Participants respond on a five-point scale indicating '1' for not at all typical of me to '5' for very typical of me. The SDQ-S and the Wayfinding surveys were used in each of the three investigations discussed herein.

3.1. *Methods*

The SDQ-S and the Wayfinding questionnaires were administered to a sample of 36 participants – 21 females and 15 males, between 18–42 years of age (mean 23.7). After completing the questionnaires, participants were introduced to and familiarised with the driving simulato – a GE-I Sim, Patrol Sim II, with a 180° field of view. Three areas were used, each with two intersecting routes. Participants drove through each area using one of three RGS formats in counterbalanced order. Before beginning the route, participants were presented with three salient landmarks (i.e. a particular billboard, a large permanently parked trailer, a grove of trees). They were asked to watch for each of the objects as they traversed the two routes in each area.

3.1.1. *Route guidance system formats*

Three formats of RGS aids were examined. One consisted of a visual map guidance system (VMGS). The VMGS was presented in north-up format and thus can be said to have been a geo-centred visual map. The driver's location while travelling through the route was presented on the moving map display in real time and they were instructed to follow a highlighted marker that was always visible on the map, indicating the direction of travel at each intersection.

A second, auditory RGS (ARGS) format consisted of presenting short auditory commands (i.e. 'turn left', 'turn right', or 'continue forward') at a normal conversational level of approximately 65 dB. The commands were always presented in an ego-centred (driver front view) perspective. The third format consisted of a dual modality route guidance system (DMRGS) presenting both the VMGS and ARGS concurrently.

Following completion of the two navigational questionnaires, participants drove through two intersecting routes in one of three areas using one of the RGS formats. Participants ultimately drove through all three areas using one of the three RGS formats in counterbalanced pairings.

After participants had driven through both routes in one area, they were asked to answer cardinal direction questions pertaining to salient features and the location of objects presented to them before beginning the routes in a new area. Some of the questions involved individual routes while others pertained to the overall area. For example, an individual route question might be: 'The large grove of trees was to the ______ of the starting point'. Participants were then to choose from among the directions provided: north; northeast; east; southeast; south; southwest; west; northwest. They were given 2 points for a correct answer and 1 point for an answer off by only 45° (i.e. if they chose 'west' and the correct answer was southwest or northwest). An example overall area question might be: 'The end point of the first route was to the ____ of the starting point of the second route'. Area questions were scored in the same manner as route questions.

Participants also completed a subjective workload assessment, the NASA-Task Load Index (TLX) (Hart and Staveland 1988). The NASA-TLX has six dimensions (mental, physical and temporal demand, performance, effort and frustration level), each rated on a 10-point scale. Participants were instructed to indicate their perception of the mental workload associated with navigating with the assistance of each type of RGS format. The unweighted average of their ratings after each drive was taken as an overall indication of their perceived mental workload.

Previous research has provided initial evidence that geo-centred maps may be more effective than ego-centred maps in facilitating cognitive map construction during navigational tasks (Azekura 2003). However, a substantial number of people have difficulty interpreting geo-centred or allocentric maps (Gugerty and Brooks 2004). It was therefore predicted that the VMGS format would benefit cognitive map formation among people with a GSD, as indicated by the SDQ-S and among people indicating a strong preference for a survey-style navigational strategy as indicated by the Wayfinding instrument. Previous research (Dingus *et al*. 1997) indicates that drivers feel that navigating is generally easy when using the auditory RGS either by itself or in combination with the visual map RGS system. It was therefore predicted that regardless of navigational strategy and ability, drivers would rate the workload of navigating with the ARGS (either alone or in the DMRGS) to be lower than when navigating with the VMGS alone.

3.2. *Results*

Significant individual differences were observed in accuracy of participants' cognitive map formation as a function of their navigational ability grouping and the type of RGS format used. Drivers reporting a high sense of awareness on the SDQ-S (Kato and Takeuchi 2003), indicating that they can generally keep track of cardinal headings even in unfamiliar places, demonstrated better cognitive map formation when using the VMGS relative to the ARGS and the DMRGS. Figure 1 gives a graphical illustration of the average number of questions answered correctly by both groups as a function of the device format used to navigate through the area.

Essentially, for these high navigational ability drivers, the ego-centric auditory RGS was insufficient for promoting cognitive map development. Contrary to expectations that the DMRGS might benefit cognitive map formation among all drivers, results indicated that, for individuals with a GSD, the redundant information actually impaired performance. High SOD individuals performed significantly worse with the dual modality relative to VMGS by itself.

Similar results were observed for individual differences in navigational strategy, as assessed by Lawton's (1994) Wayfinding instrument. Participants reporting high use of a survey strategy demonstrated better cognitive map formation when traversing routes with the VMGS. Figure 2 provides a graphical illustration of the average number of correctly answered questions for individuals reporting high and low survey strategy use as a function of RGS format.

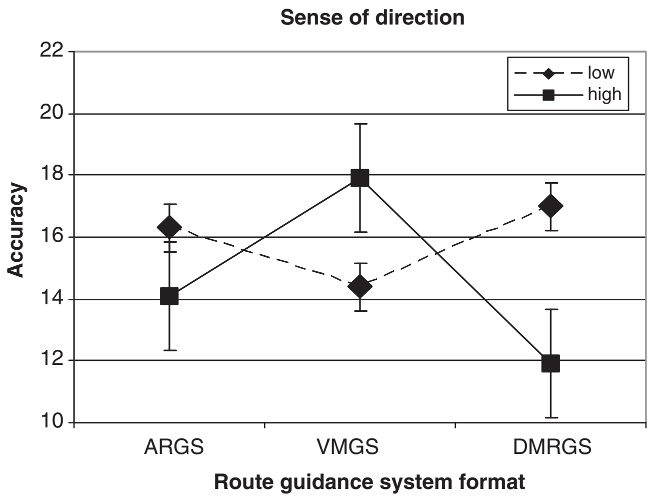

Figure 1. Accuracy of the cognitive map questions as a function of sense of direction and route guidance system format. ARGS = auditory route guidance system; VMGS = visual map guidance system; DMRGS = dual modality route guidance system.

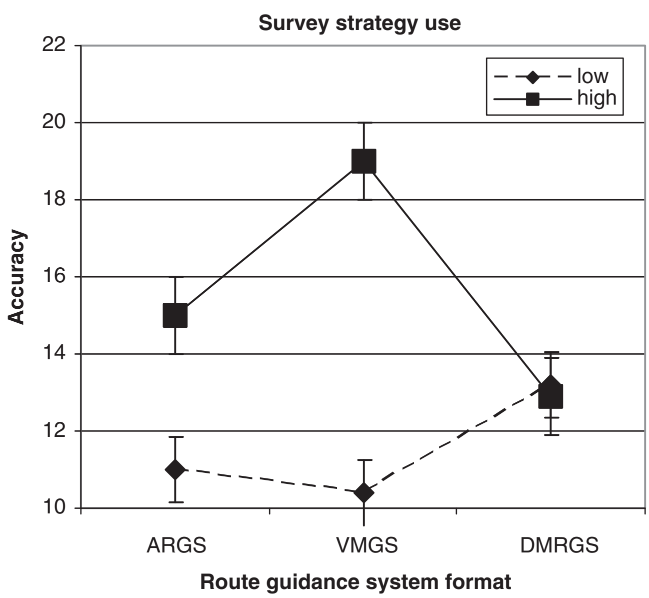

Figure 2. Accuracy of the cognitive map questions as a function of use of survey style wayfinding strategy and route guidance system format. ARGS = auditory route guidance system; VMGS = visual map guidance system; DMRGS = dual modality route guidance system.

As illustrated in Figure 2, providing both auditory and visual information in the DMRGS disrupted cognitive map formation in the high survey strategy group. However, the redundant information provided by the DMRGS improved cognitive map formation among the low survey strategy use individuals.

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As expected, all participants, regardless of SOD and wayfinding strategy, reported that providing auditory guidance (either alone or in combination with the visual guidance) required lower levels of mental workload to traverse the routes. Recall that participants were specifically asked to distinguish between simply following the navigational directions and forming a cognitive map. More details regarding these results are presented in an earlier publication (Furukawa *et al*. 2004). For the present purposes, a brief discussion will be focused on the major implications of these results for considering individual differences when designing and implementing route guidance information systems.

3.3. *Discussion*

These results support previous research indicating that auditory guidance facilitates the task of wayfinding, while visual map guidance tends to facilitate cognitive map formation. However, more germane to the current thesis is that individual differences were observed in cognitive map formation as a function of display modality. Individuals with a PSD benefited from auditory guidance information, with or without the concurrent visual map. Conversely, individuals with a GSD had the highest cognitive map development when provided with the visual map format alone. These GSDs experienced significant performance impairment when auditory guidance was provided concurrently with visual map information, though they seemed to perform reasonably well with auditory guidance only. Thus, a completely opposite pattern of results can be seen in the concurrent auditory and visual format condition depending on whether participants were high or low in navigational ability.

The results of this investigation also underscore the importance of considering individual differences in designing in-vehicle RGS. An optimal RGS would assist individual drivers with the wayfinding task and would also facilitate the establishment of a cognitive map of the unfamiliar area.

Further, the SDQ-S (Kato and Takeuchi 2003) proved to be a sensitive index of distinguishing between individual differences in navigational ability in a US sample. The next section looks at its ability to predict the type of working memory resources that individuals use to perform route-learning tasks.

4. Experiment 2

Experiment 1 demonstrated that not only do people differ in their spatial and navigational abilities, but that these differences impact their use of different forms of navigational aids. It also provided support for the ability to predict these individual differences with self-report questionnaires. Kozlowski and Bryant (1977) were arguably one of the first investigative teams to examine whether or not self-report is a valid indicator of navigational ability. They observed good correspondence between perceived ability and pointing accuracy to visually obstructed landmarks. More recently, investigators have used a wide variety of self-report and performance methods to examine individual differences, often with mixed results. This experiment further validates the SDQ-S (Kato and Takeuchi 2003) as a means of distinguishing between navigational ability groups by determining if it predicts the type of working memory processes used during route learning (see Baldwin and Reagan in press).

Several previous investigations indicate that different navigational strategies rely on different working memory resources (Garden *et al*. 2002, Saucier *et al*. 2003).

As previously discussed, Saucier observed that good navigators tend to rely on survey strategies that make use of visuospatial processes while poor navigators rely on verbal route strategies. Garden and colleagues observed differential patterns of route learning performance as a function of whether or not individuals reported a tendency to use map-like representations when learning routes and the type of interference task they performed during actual route learning. Specifically, individuals indicating that they tended to use map-like representations were classified as 'high spatial ability', while those reporting low tendencies in this area were classified as 'low spatial ability'. Relative to low spatial ability individuals, the high spatial ability group exhibited greater disruption (more navigational errors and pauses) when traversing for the first time a route they had learned while concurrently performing a spatial tapping task designed to task their visuospatial working memory resources. Conversely, the low spatial ability group, relative to both the high spatial ability group and their own performance for routes learned while performing the spatial tapping task, exhibited greater route-learning disruption for routes learned while performing a concurrent task designed to disrupt verbal processing.

Garden and colleagues classified their participants on the basis of two questions, both related directly to the use of map-like representations. Additional self-report items appear to have been administered in this Italian sample of adults; however, neither the scores on these items nor their potential contribution to a classification structure were provided. The extent to which their results would generalise to another sample is therefore difficult to determine.

Experiment 2 examined both the factor structure of the SDQ-S and its ability to predict the type of working memory resource that individuals would use to learn novel routes. Kato and Takeuchi (2003) used the SDQ-S to obtain groups of individuals with self-assessed GSD and PSD in a sample of Japanese adults. GSDs made significantly fewer wrong turns in a route-learning task than PSDs. A concurrent verbal protocol indicated that GSDs used a number of visuospatial strategies (e.g. cardinal directions, salient landmarks), while PSDs tended to use ineffective verbal strategies (such as memorising house numbers).

It was reasoned that the SDQ-S could be used to distinguish between GSD and PSD groups and that GSDs would demonstrate greater reliance on visuospatial working memory processes to learn novel routes, while PSDs would favour use of verbal strategies. Using a paradigm modelled after Garden *et al.* (2002), route learning was examined as a function of SOD and performance of a concurrent interference task designed to place demands on either visuospatial or verbal working memory resources (spatial tapping or articulatory suppression, respectively). GSDs were expected to exhibit greater route-learning interference when required to perform the concurrent spatial interference (SI) task, while PSDs were expected to experience greater disruption from the verbal interference (VI).

4.1. *Methods*

4.1.1. *Participants*

The SDQ-S (Kato and Takeuchi 2003) was administered to an initial sample of 191 participants. Responses from this sample were subjected to structural equation modelling, which identified three independent factors, use of cardinal directions, maps and landmarks. Items contributing to each of these factors were averaged and then these averages were summed to form composite scores for overall SOD. The SDQ-S was then administered to additional respondents for a total sample size of 234. From this sample, respondents scoring a composite score of 1 SD above or below the grand mean composite score were tagged as potential participants. Of 234 survey respondents, 42 scored above the criterion (19 female), and were therefore classified as GSDs, and 41 scored below (31 female) and were classified as PSDs. From this group of individuals, 42 participants were recruited for participation in Experiment 2, 20 GSDs (11 females) and 22 PSDs (15 females) ranging in age from 18–44 years.

4.1.2. *Routes*

Routes were created in an indoor virtual environment using a commercially available video game. Each route had 11 turns and took approximately 2.5 min to traverse. Participants controlled the character by computer mouse.

4.1.3. *Interference tasks*

Interference tasks were modelled after those used by Garden *et al*. (2002). The SI task consisted of tapping a sequence of keys on a keypad in forward and reverse order. The VI task involved repeating a string of nonsense syllables in forward and reverse order.

The main dependent measures of interest were the number of navigational errors made and time taken when attempting to traverse the routes from memory for the first time. Garden *et al*. (2002) found that time taken to traverse the routes was related to the number of pauses, indicating indirectly the degree of certainty in route memory. Interference task performance was recorded and analysed.

4.2. *Results*

As expected, PSDs demonstrated more difficulty learning the routes in general. Regardless of the interference task they were required to perform during the learning trial, when traversing routes on their own for the first time, they tended to make more navigational errors and take longer to traverse the route than the GSDs. Analysis of their subjective workload scores (as obtained on the NASA TLX) indicated that PSDs found the task more difficult than GSDs. These results provide further validation for using the SDQ-S as a classification instrument for individual differences in navigational ability.

4.2.1. *Errors*

As predicted, a significant interaction between SOD group and interference task was observed, indicating that GSDs made fewer errors in routes learned under VI (mean 1.75) relative to PSDs (mean 4.23). GSDs also made more errors traversing routes learned during SI (mean 3.80) relative to VI (mean 1.75) interference.

4.2.2. *Time*

Also as predicted, a significant interaction between SOD group and interference task was also observed for time taken to complete routes. As illustrated in Figure 3, GSDs took more time to complete routes they had learned in the SI relative to the VI. Conversely, PSDs took less time to traverse routes learned during SI relative to VI.

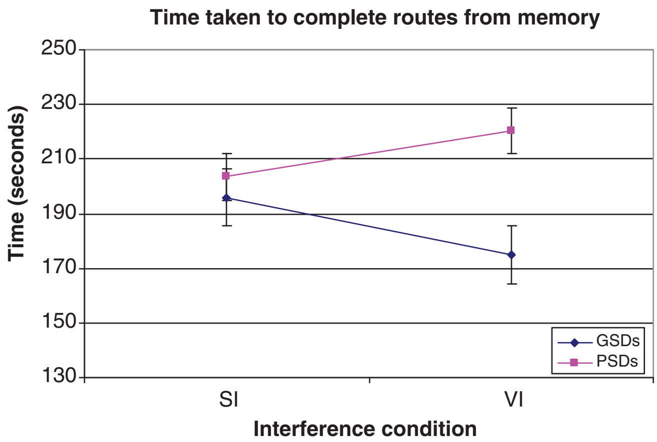

Figure 3. Time required to traverse routes from memory as a function of sense of direction and interference task experienced during route learning. GSD = good sense of direction; PSD = poor sense of direction; SI = spatial interference; VI = verbal interference.

4.3. *Discussion*

The purpose of Experiment 2 was two-fold. The first goal of providing further validation for the use of the SDQ-S for distinguishing between individual differences in navigational abilities was accomplished. Using groups established based on their self-reported abilities on the SDQ-S, it was observed that individuals with a GSD learn novel routes more effectively and report lower mental workload for doing so.

Regarding the second major goal of Experiment 2, confirmatory evidence was found that individuals with a GSD tend to rely on visuospatial working memory processes to learn novel routes. Conversely, individuals with PSD rely more heavily on verbal strategies than visuospatial strategies (Baldwin and Reagan in press). Implications of these results will be discussed further in the general discussion. The next section outlines the third investigation, which sought to determine if older navigators tend to rely on the same types of information as their younger counterparts.

5. Experiment 3

The last experiment examined whether older drivers need and want the same type of navigational information as younger drivers. Population ageing in the culture of driving has resulted in more individuals over the age of 65 years continuing to drive than in any previous generation (Ball and Owsley 1991, National Highway Traffic Safety Administration 2005). As a group, these older drivers tend to drive more miles than their age-matched cohorts of previous generations and they are over-represented in traffic fatalities in terms of the number of miles they drive.

Navigating while driving is a challenge for many motorists, but this is particularly true for many older drivers (Burns 1999). As previously mentioned, providing navigational assistance in the form of in-vehicle devices can potentially reduce some of the attentional demands of navigating. These systems may be of particular benefit to older drivers, but only if they are designed in accordance with the capabilities and preferences of ageing adults (Baldwin 2002). Towards this aim, Experiment 3 sought to determine if older adults

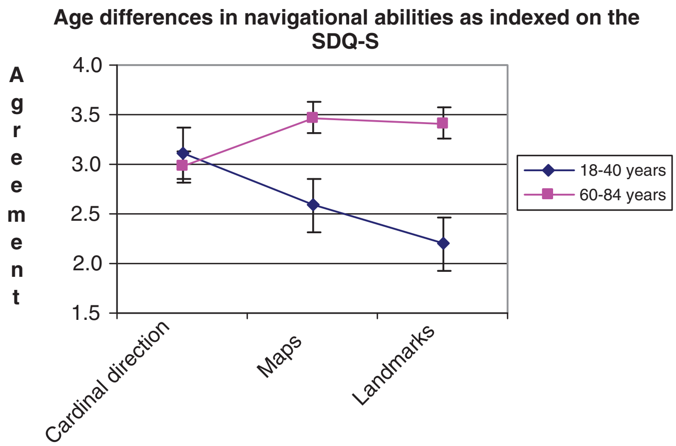

Figure 4. Age differences in use of the dimensions of the short version of the Sense of Direction Questionnaire (SDQ-S).
Note: Higher numbers indicate more difficulty with this type of information.

use the same navigational or wayfinding strategies as younger adults. Performance strategies shifts have been observed among older adults in previous investigations. For example, older adults tend to rely more heavily on verbal strategies than young adults, even in situations where performance of a primary task is more likely to be disrupted by use of a verbal strategy (Hartley *et al.* 2001). It was therefore reasoned that older adults would tend to report greater reliance on verbal route information than younger navigators.

5.1. *Methods*

Kato and Takeuchi's (2003) SDQ-S and Lawton's (1994) Wayfinding questionnaire were administered to 92 young (18–34 years) and 32 older (60–85 years) participants. SDQ-S responses were compiled into composite scores for each of three dimensions identified in Experiment 2, cardinal directions, maps and landmarks. Wayfinding responses were compiled into survey and route dimensions.

5.2. *Results*

Individual items from the SDQ-S composing the dimensions of ability to use cardinal directions, maps and landmarks were averaged for all respondents. As shown in Figure 4, older drivers reported more difficulty using both maps and landmarks than their younger counterparts. However, there were no significant differences in reported ability to use cardinal directions between the young and older drivers, presumably because younger drivers also found this type of information considerably difficult.

There was a significant age difference in navigational strategy use, as indexed by the Wayfinding Questionnaire. As illustrated in Figure 5, both younger and older adults reported a greater tendency to use a route wayfinding strategy. But this was particularly true of younger adults, while older adults indicated relatively high use of both types

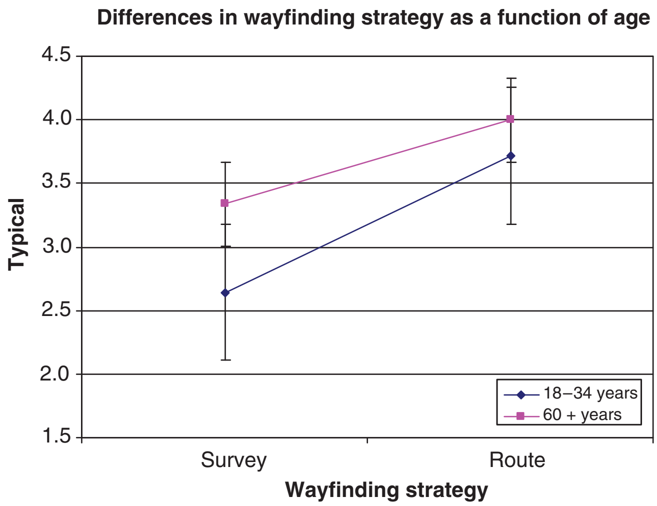

Figure 5. Age differences in use of survey and route wayfinding strategies.

of strategies. Recall that the survey strategy includes use of cardinal directions, a type of information young adults in this sample report having particular difficulty with.

5.3. *Discussion*

Contrary to expectations, no age differences in preference for verbal route information were observed in the current sample of navigators. Adults over age 60 years did report a stronger preference for route information than for survey information; however, so did navigators under the age of 35 years. Contrary to expectations, older drivers reported greater preference for survey strategy information than did their younger counterparts. This may reflect a general desire on the part of older drivers to receive as much information as possible to assist with the challenge of wayfinding. However, it is also possible that this result reflects a strong dislike for the use of cardinal heading information among the younger participants. Anecdotally, in Experiment 1, many younger participants required instruction as to how to interpret cardinal heading information. Therefore, before beginning the experimental trials, a compass with cardinal heading information and several practice questions of that type were provided. Older adults in Experiment 3 reported greater familiarity with and use of cardinal heading information than the younger adults.

6. General discussion

Results of the three experiments reported herein point to the importance of considering individual differences in the design and implementation of in-vehicle navigational devices. Experiment 1 indicated that display modality differentially impacts navigators with different SOD abilities. All drivers reported lower mental workload when using the auditory guidance instructions for basic wayfinding, but individual drivers differed in their ability to form cognitive maps of the areas they had driven through using each of the formats. Auditory guidance facilitated cognitive map formation for drivers with a PSD and those who preferred route wayfinding strategies. Conversely, visual map guidance facilitated cognitive map formation for drivers with a GSD, but only when it was provided by itself, without concurrent auditory directions. It is likely that PSD drivers could simply ignore the visual map and, therefore, while they did not benefit from its presentation, they were not distracted by it either. Conversely, drivers with GSD may have found it more difficult to ignore the auditory information in order to concentrate on their preferred visual map information. That the visual display presented allocentric directions on a north-up map while the auditory guidance showed ego-centric directions, poses an additional challenge. The two different orientations might have made it even more difficult for a person who was either trying to incorporate both types of information or trying to ignore the auditory information.

The results of Experiment 1 provided initial behavioural validation of the use of the SDQ-S (Kato and Takeuchi 2003) for distinguishing between different categories of navigators in a US sample. This validation was extended in Experiment 2. The SDQ-S is an easy to administer, self-report questionnaire that can be used for general classification of individuals with GSD vs. PSD. As evidenced in Experiment 1, these groups differ in the ease with which they learn novel routes and the navigational format that best assists them with accomplishing the learning task. Experiment 2 indicated that the strategies used by these groups rely on different types of working memory processes.

Experiment 2 indicated that individuals with a GSD demonstrate a tendency to use strategies that rely on visuospatial working memory to learn novel routes – as evidenced by GSDs experiencing greater disruption in the route-learning task when they had to perform a concurrent visuospatial rather than VI task. Conversely, PSDs exhibited greater performance decrements when learning routes while subjected to a verbal rather than a visuospatial interference task. Although indirect, these results suggest that GSDs would expend greater attentional effort during navigational tasks when faced with competing demands for visuospatial working memory resources rather than verbal demands. The GSD individual, therefore, might be expected to more easily carry on a conversation while navigating and learning an unfamiliar route than the PSD individual. Any type of VI, competing speech for instance, could be expected to disrupt the PSD individual more than the GSD. Conversely, though perhaps more rare in the automobile, a competing visuospatial task could be expected to disrupt the route learning of a GSD individual more than a PSD.

Experiment 3 examined the navigational strategies and abilities of older adults. Adults over the age of 60 years report having more difficulty than their younger counterparts in a variety of different navigational tasks (i.e. reading maps, remembering landmarks). However, older adults report less difficulty using cardinal heading information relative to both the other two types of information and relative to their younger counterparts. Support has been found in the past for self-report assessments of navigational abilities and the results of Experiments 1 and 2 support the use of the SDQ-S instrument used here. Navigation in unfamiliar areas is such a particular challenge to many older drivers that these results suggest the need for further investigations. It is extremely uncommon, if possible at all, to receive cardinal heading information in currently available systems providing auditory guidance directions. Previous research indicates that older drivers benefit in particular from auditory rather than visual guidance navigational formats (Dingus *et al*. 1997). Results of Experiment 3 suggest that the most effective system might be cardinal heading information presented in an auditory format. Reagan and Baldwin (2006) found a slight benefit for including cardinal heading information in addition to standard turn-by-turn auditory guidance information amongst a sample of young drivers.

Young people in Reagan and Baldwin's earlier sample, as well as young people in the Experiment 3 sample, report greater difficulty using cardinal heading information than other types of information (i.e. such as landmarks). Since older adults report a preference for cardinal heading information, its inclusion as a supplemental type of information might particularly benefit older drivers.

7. Conclusions

Together, the results of the three experiments reported here emphasise the need to consider individual differences when designing and implementing navigational systems. The results indicate that self-report questionnaires can be used to reliably assess strategy differences that impact performance. Individuals tending to have a PSD and low use of survey-type strategies demonstrate greater cognitive mapping performance when exposed to a verbal navigational aid. Further, these individuals demonstrate some improvement from exposure to a visual map in conjunction with the verbal aid. Conversely, individuals with GSD and those who tend to use survey strategies benefit from visual-map style navigational aids and are disrupted by concurrent presentation of the visual and verbal formats. Individuals relying on each of these strategies differentially utilise verbal vs. visuospatial working memory processes and are thus susceptible to performance disruption from different types of interference. Increased difficulty with navigation in unfamiliar areas is commonly found among older adults. The type of information provided to assist younger individuals with the navigational task may not be optimal for older adults. Older adults benefit from auditory RGS aids but report greater reliance on map and cardinal heading information relative to their younger counterparts. Providing supplementary information in auditory RGS may particularly benefit older drivers. In summary, well-designed guidance systems that take into account both the user's capabilities as well as his or her preferred strategies have the potential to increase transportation safety and efficiency.

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