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How Attitudes about Navigation are Linked to Navigation Ability: Impact of Exploration Tendency and GPS Dependency

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by

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ABSTRACT

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by

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A spectrum of individual differences exists in navigation ability, measured by different navigation tasks. The underlying cognitive mechanisms have been discussed for decades. However, possible motivational and emotional dispositions related to navigation highlighted in the current studies call for more attention. After developing three new self-report surveys, it was found that people with low spatial anxiety have high tendency to explore different places and low tendency to rely on Global Positioning Systems (GPS) during navigation. Also, these navigation behaviors can be treated as partial mediators to explain how anxiety influences navigation ability. Growth mindset in navigation ability (a belief in malleability of navigation ability), serving as an intrinsic motivation to train people themselves on more effective navigation in daily life, explains a unique portion of variance in navigation ability. This study paves a new path for understanding the development of navigation ability.

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I. Introduction

A. *Overview*

Navigation ability, also sometimes referred to as environmental spatial thinking ability, is an essential cognitive ability in daily life. We rely on navigation ability to maintain a sense of orientation and location during movement in an environment. Also, from time to time, we need to learn a layout of a new environment, find the quickest way to reach a place and orient in unfamiliar places. Given that successfully achieving navigation tasks requires multiple cognitive processes, including spatial learning, spatial updating and decision making, it is suggested that developing navigation ability requires effort for many people (Weisberg & Newcombe, 2018). Consequently, completing navigation tasks, which require learning and applying spatial information and knowledge, might depend on motivation (willingness to make an effort) and strategy (approaches to learning efficiently) and not just ability. This view is consistent with Newcombe's (2018) idea that individual differences in navigation ability are largely about learning and variations in learning. Also, previous studies suggest that people's spatial ability is malleable (Newcombe, 2018; Uttal & Cohen, 2012; Uttal et al., 2013), although the malleability of navigation ability is barely discussed in the psychological literature. The current study aims to investigate how motivations and attitudes affect navigation ability. Specifically, it addresses how people's attitudes about navigation and motivation to learn their environments affect their navigation behaviors, and consequently, how these behaviors, resulting in different navigation experience, eventually affect their navigation performance.

B. ***Motivational Dispositions***

To date, researchers have not fully studied the effect of motivation on navigation performance. In one recent study, Weisberg and Newcombe (2016) investigated the effect of monetary incentive to evaluate participants' accuracy in generating two different routes in Virtual Silcton, a desktop virtual environment (Weisberg, Schinazi, Newcombe, Shipley, & Epstein, 2014). Their results did not suggest that monetary incentive was motivating. However, monetary stimulus is an extrinsic motivator in contrast with an intrinsic motivator, such as mastery-oriented goal or self-enhancement goal (Taylor, Lerner, Sherman, Sage, & McDowell, 2003). Theoretically, if participants have a self-image that they are poor navigators, even if they are given a monetary incentive, it may not create a strong drive to perform well compared to the drive for self-enhancement. For example, participants may reason that "I know I am not a good navigator and it is not a big deal for me". Consequently, even though Weisberg and Newcombe (2016) failed to find effective incentive does not preclude other motivational dispositions in navigation. Functions of motivation raised in this paper include encouraging people to develop effective navigation strategies in daily life, including the tendency to explore different places and routes in a new environment or constructing a flexible mental representation of a new environment. Such effects are hard to study in a one-time in-lab experiment.

C. ***Emotional Dispositions***

Emotional dispositions may affect the link between people's performance in navigation paradigms and their raw navigation capacity. One of important emotional dispositions is spatial anxiety (Cashdan & Gaulin, 2016). In an early paper, Lawton (1994) suggested that high spatial anxiety was linked to less tendency to use an orientation strategy compared to a

route strategy. A route-based strategy, which is sometimes called a response strategy, refers to remembering the route-based spatial information, such as a sequence of landmarks, turns or intersections from a first-person perspective (Tolman, 1948). An orientation strategy, which is sometimes called a survey strategy, map-based strategy, or place strategy, refers to using a cognitive map constructed and represented in human minds to estimate distance or direction in order to understand and remember the spatial relationships between different objects in the environment (Hund & Padgitt, 2010; Munzer & Holscher, 2011; Pazzaglia & Beni, 2001). Hund and Minarik (2006) found that survey strategy and low spatial anxiety are related to fewer navigation errors, although the direction of causality is still unclear. It is possible that people's anxiety impedes their success in tasks, but it is also possible that people are anxious due to awareness of their insufficient navigation ability (Weisberg & Newcombe, 2018).

The present study highlights both possible directions of causal effects. That is, high spatial anxiety may be initiated by several failures in navigation experiences, but more importantly, these failures may cause people to withdraw in later daily life, so that their development of navigation ability is impeded. After having motivations to learn an environment, or reducing anxiety, people may have more adaptive navigation behaviors which are beneficial for developing navigation abilities.

D. *Navigation Behaviors*

One possible way of developing navigation ability is enjoying challenges during navigation tasks and training navigation strategies from these challenges (Lovden et al., 2012; Woollett, Spiers, & Maguire, 2009). A previous personality study using the Big Five scale supports this idea (Condon et al., 2015). In this study, people's self-rating of their

navigation ability, measured by the Santa Barbara Sense of Direction (SBSOD: Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002) was positively related to Openness (adventurousness), Extraversion (energy and approach behavior), and Conscientiousness (attention to detail, organization, and diligence).

Additionally, studies related to exploration (Gagnon et al., 2018) and active learning (Chrastil & Warren, 2012) also revealed connections between people's spatial learning procedures and their navigation performance. That is, if people explore more and attempt to actively build representations of their environment actively, their performance in navigation tasks will be better.

In addition to exploration, another behavior under discussion is using a navigational aid system or Global Positioning System (GPS) accessible on mobile phones or cars. Ishikawa, Fujiwara, Imai, and Okabe (2008) compared participants' navigation behaviors and acquired spatial knowledge in GPS, paper-map, and direct-experience groups. Their study revealed that compared with paper-map users and direct-experience navigators, GPS users had more imprecise performance across different tasks, including more stops during navigation, traveling more slowly, more direction errors, less accurate sketch maps and they rated wayfinding tasks as more difficult. Also, Gardony, Brunye, and Taylor (2015) employed a dual-task methodology to study the effect of GPS on navigation performance and proposed that navigating following GPS seems to inhibit participants' spatial learning procedure due to divided attention. Ruginski, Creem-Regehr, Stefanucci, and Cashdan (2019) developed mediator models to demonstrate that GPS usage may impede people's environmental learning by influencing people's perspective taking ability and mental rotation ability.

Taking these studies together, I hypothesized in this study that people's navigation behaviors will eventually influence their performance in navigation tasks. Specifically, I hypothesized that high exploration tendency helps participants gain more opportunities to form flexible and accurate spatial representations and improve their navigation behaviors, but high GPS dependency impedes these processes.

E. *Development of Navigation Ability*

The links between attitudes, learning behaviors and achievement discussed above follow a similar logic to the theory of Growth Mindset which refers to a mindset of believing the malleability of their ability. Research studies related to growth mindset in the past three decades show that a single belief with regards to malleability of intelligence leads to a series of attitudes and actions, which interact with each other, and eventually influence individual achievement (Castella, Krista, & Byrne, 2015; Dweck, 1999; Dweck & Leggett, 1988). The mechanism underlying the effect of growth mindset on achievement is that it influences how much people value efforts (Dweck &Leggett, 1988). That is, people with growth mindset are more likely to value efforts or approach challenges to achieve their learning goals, even though they are anxious or facing challenges. These attitudes and behaviors will eventually lead them to higher achievement than people with fixed mindset, who don't believe their abilities or talents can be improved. People with fixed mindset are more likely to withdraw from facing challenges and show other helpless behavior patterns. With the development of mindset theories, the belief of malleability and improvement (in intelligence as well as other properties) not only functions in the school settings (Robins & Pals, 2002) but also in parenting, business or organization management, and intimate relationships (Dweck, 2006). However, no previous research has investigated how growth mindset influences people's

spatial learning processes and navigation ability, even though the link between the malleability of spatial thinking ability and STEM achievement has been under active discussion in recent years (Uttal & Cohen, 2012; Uttal et al., 2013).

In the situation of solving navigation tasks, I hypothesize that people with growth mindset will explore different places or routes in the environment and tend to approach challenges so that they do not rely on GPS too much. In contrast, I predict that people with fixed mindset will avoid opportunities for exploration and rely more on their GPS. These attitudes, including emotional dispositions and intrinsic motivational dispositions, theoretically will motivate navigators to pay more or less attention to their surroundings in their daily life and eventually, these behaviors will help them show better or worse navigation performance. These ideas echo Bryant's seminal work in 1982. After studying the relationship between people's personality and sense of direction, Bryant concluded that engaging spatial environments differently mediates the connections between people's personality traits, such as sociability and self-acceptance, and their sense of direction (Bryant, 1982). However, Bryant did not actually measure people's "engagement" and the advent and subsequent wide spread usage of GPS happened much later than when that work was conducted.

F. *Measures of Navigation Ability*

Navigation is a multidimensional ability (Montello, 2005; Newcombe, 2018), which means it is hard to measure by using one standard test. In the present study, people's navigation ability was indirectly measured by two perspective taking tasks (Hegarty &Waller, 2004; Kozhevnikov & Hegarty, 2001; Montello, Lovelace, Golledge, & Self, 1999) and a self-report questionnaire, the Santa Barbara Sense of Direction scale (SBSOD;

Hegarty et al., 2002). In the perspective taking tests, a two-dimensional array of objects (Object Perspective Task) or a fictional map (Map Perspective Test) are displayed, and participants estimate the direction to a target object or a place location in the map from an imagined perspective. Previous studies show that people's perspective taking ability is partially disassociated from their spatial visualization ability (measured by mental rotation task) and is more related to people's large-scale spatial ability or navigation ability than spatial visualization (Galati, Weisberg, Newcombe, & Avraamides, 2018; Hegarty & Waller, 2004; Holmes, Marchette, & Newcombe, 2017; Kozhevnikov & Hegarty, 2001; Weisberget et al., 2014).

In the SBSOD, participants rate their own environmental spatial abilities in everyday wayfinding tasks. In the original paper developing the SBSOD scale, researchers tested the validity of SBSOD and found it is significantly correlated with multiple navigation tasks to small or moderate extent. In last seventeen years, a growing number of studies also add more evidence to show that SBSOD score is significantly correlated with performance measures in various navigation tasks (Hegarty, Burte, & Boone, 2018). Thus, using the SBSOD to test people's navigation ability may be a promising starting point to understand diverse factors related to people's navigation ability.

G. *Present Studies*

The present studies aimed to address the following questions. First, what are the associations between people's attitudes about navigation, navigation behaviors, and ability? Specifically, I examined correlations between people's growth mindset in navigation ability, spatial anxiety, exploration tendency and GPS dependency. The second question asks whether navigation behaviors, namely exploration tendency and GPS dependency, can be

treated as mediators between the link between attitudes about navigation and navigation ability, as shown in Figure 1.

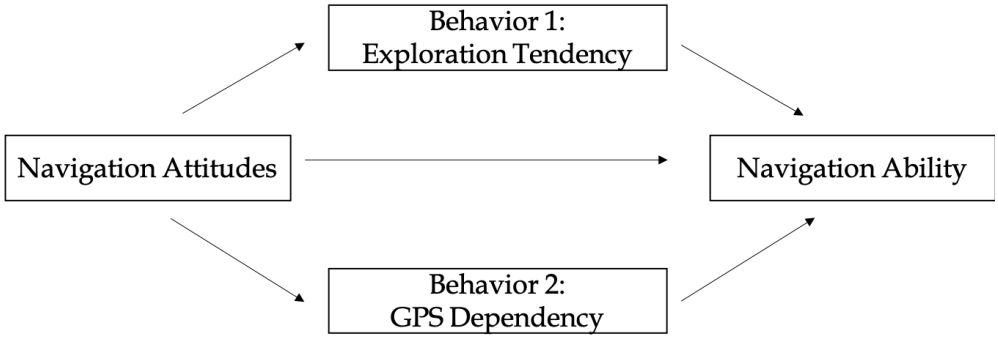

Figure 1. **The illustration of the hypothesized mediator model.**

The main goals of Study 1 were to develop new scales to measure participants' growth mindset in navigation ability, exploration tendency, and GPS dependency and examine the correlations between the measures. Based on the results of Study 1, these scales were further developed in Study 2. Importantly, multivariate regression analysis and mediator analysis were conducted in Study 2 to investigate the effects of motivational and emotional dispositions on navigation ability and examine the proposed mediation effects of exploration tendency and GPS dependency.

It is also worth noting that gender differences in navigation are well-documented (Boone, Gong, & Hegarty., 2018; Cashdan & Gaulin, 2016; Gagnon et al., 2018; Padilla, Creem-Regehr, Stefanucci, & Cashdan, 2017). Although gender differences are not the main focus of this study, gender differences in attitudes, learning behaviors and navigation ability are reported in Study 2, as they could give more clues to understand the mechanisms underlying gender differences in navigation for future studies.

II. Study 1

A. *Methods*

1.Participants

One hundred twenty-three undergraduate students (74 females and 49 males) recruited from the Psychology Subject Pool at the University of California, Santa Barbara participated in this study for course credit.

2. Materials

Measure of General Growth Mindset.

The self-theory version of the Implicit Theories Intelligence scale (Castella et al., 2015) was used to measure participants' general growth mindset (GGM). It reworded 8 items in the original questionnaire (Dweck, 1999, 2006) to reflect a first-person claim about the malleability of a person's own intelligence. Eight items were split into 4 incremental items, like "I believe I can always substantially improve my intelligence level," and 4 entity items, like "My intelligence is something about me that I personally can't change very much." The entity items are reverse scored. Research to date shows that this scale has good internal consistency, $\alpha = .90$. In the present study after averaging 8 items, the possible scores range from 1 to 5 where a higher score indicates having more general growth mindset.

Measure of Growth Mindset in Navigation Ability.

Based on the scale for general growth mindset, the measure of growth mindset in navigation ability was developed. The words related to "intelligence" were replaced by words related to "navigation ability" (See Appendix A for scale items). In addition, this scale used a 7-point scale (in contrast to a 5-point scale) to diminish the effect of method

bias caused by commonalities in the scale anchors and formats (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003; Tourangeau, Rips, & Rasinski, 2000). The scoring method was similar with that of the GGM scale (4 items are reverse scored). A higher score indicates having more growth mindset in navigation ability. However, to make the results comparable, the final average scores were linearly transformed from ranging 1-7 to ranging 1-5.

Measure of Self-report Sense of Direction.

The Santa Barbara Sense of Direction Scale was employed to imply participants' navigation ability (Hegarty et al., 2002). This scale consists of 15 Likert-type items measuring people's self-reported environmental spatial ability or "sense of direction". Participants selected 1 ("strongly agree") to 7 ("strongly disagree") with the two endpoints labeled by anchors. Of the 15 items, 7 items were stated negatively, for example, "I very easily get lost in a new city," and 8 items were stated positively, for example, "I am very good at judging directions." Negative items were reverse scored and the average of the 15 items was used as the measure of self-reported sense of direction. A higher a score indicates a better sense of direction. Previous research (Hegarty et al., 2002) has shown that the internal reliability of the scale is .88.

Measure of Spatial Anxiety.

Lawton's Spatial Anxiety Scale (Lawton, 1994) was employed to measure the level of spatial anxiety that participants would experience in eight scenarios. A sample scenario is "Leaving a store that you have been to for the first time and deciding which way to turn to get to a destination." Participants used a 5-point scale labeled with "A great deal", "A lot," "A moderate amount", "A little" and "None at all" to rate their anxiety in these situations. The average of the 8 items was used as the measure of the spatial anxiety. The potential

scores range from 1 to 5, and a higher score indicates more anxiety experienced during navigation.

Measure of Exploration Tendency.

A new scale was developed to measure a person's tendency to explore different places and routes under different situations (Appendix C). The 4-item scale has two positively stated items and two negatively stated items. An example of a positively stated item is "if I have a chance, I like to explore different routes to get to my destination." An example of a negatively stated item is "I prefer to follow my daily route or the way I have known before to get to my destination." Participants used a 7-point Likert-scale with the labels "Strongly agree; Agree; Somewhat agree; Neither agree nor disagree; Somewhat disagree; Disagree and Strongly disagree" to represent their attitudes. A higher score indicates that participants are more likely to explore new places or routes.

Measure of Global Positioning System Dependency.

To measure Global Positioning System (GPS) Dependence, 8 scenarios were used based on a revised version of Lawton's Spatial Anxiety Scale (Lawton & Kallai, 2002). Instead of rating anxiety, this scale asks participants to rate how often they use their GPS in these scenarios. Participants used a 5-point scale with the labels "Always; Most of the time; About half the time; Less than half of the time; Never" to indicate their answers. The potential scores range from 1 to 5, and a higher score indicates that participants are more likely to use GPS applications accessible on mobile phones or cars during navigation. All of these five

questionnaires were presented on the Qualtrics online survey platform and participants' responses were recorded on this platform.

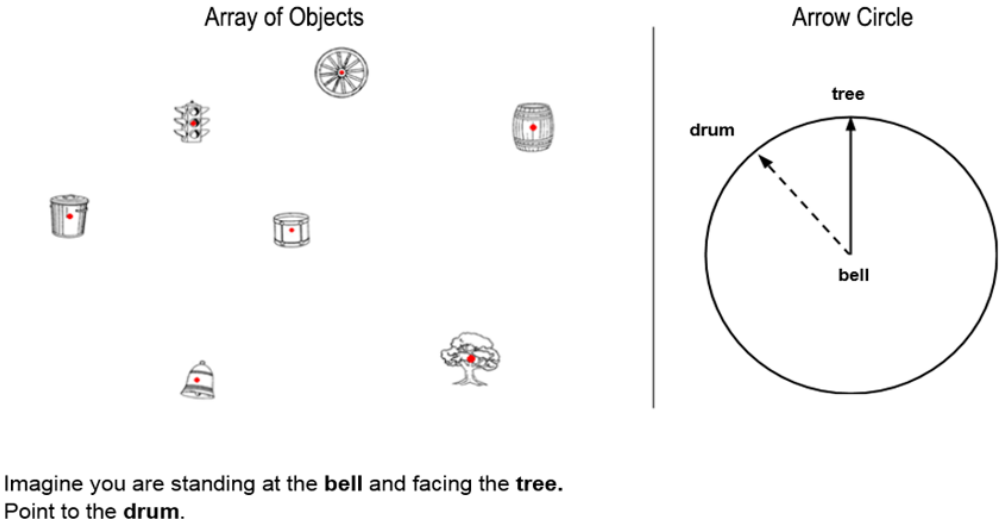

Figure 2. **A sample trial of the Object Perspective Test (Friedman et al., 2019)**
Note: The dash line indicates the correct answer. In each trial no dash line shows up. Participants clicked the arrow circle to initiate the second line pointing to a direction and drag the line until participants are confident that the second line is pointing to the direction they are required to indicate.

Measure of Perspective-taking ability.

Perspective-taking ability was measured by two in-lab computer-based tasks, a revised version of the Object Perspective Test (OPT) and a revised version of the Map Perspective Test (MPT) (Friedman, Kohler, Gunalp, Boone, & Hegarty, under review; Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001; Montello, Lovelace, Golledge, & Self, 1999). The tasks were written in Eprime (PST Software) and the trials were presented on ASUS generic monitors with 1920x1080 resolution. In the revised Objective Perspective Test, an array of 7 non-directional objects was used as the stimulus (See Figure 2) and was displayed on the left half of the monitors. For each item, the participant was asked to imagine being at an object, facing another object and to indicate the direction to a third object using the arrow

circle. The score for each item was the absolute directional error. A participant's performance in this task was represented by an average absolute error across all items. Twelve items were represented to each participant in a random order. The Map Perspective Test (MPT) shares similar instructions, implementation and score rules with the OPT, except that participants need to make direction based on a fictitious map (See Figure 3) and the twelve items were represented in a fixed order.

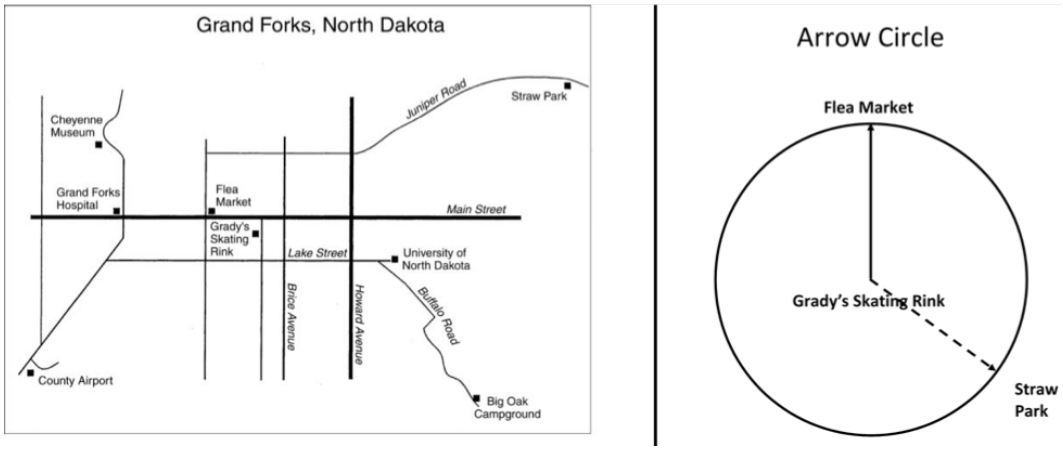

Figure 3. **A sample trial of the Map Perspective Test**
Note: This task is based on a fictitious map of Grand Forks (Montello, et al., 1999). The dash line indicates the correct answer. In each trial no dash line (correct answer) shows up. Participants clicked the arrow circle to initiate a second line pointing to a direction and drag the line until participants are confident that the second line is pointing to the direction they are required to indicate.

3. Procedure

All participants responded to the 6 questionnaires and 2 perspective-taking tests in a fixed order in a lab cubicle either alone or in groups of two but working independently. Upon arrival, participants were given a consent form. Then, they began to complete the questionnaire measuring general growth mindset and growth mindset in navigation ability without a time limit. Following the two questionnaires, the Object Perspective Test (OPT) was given including the instructions and three practice trials. The participants were then told

that they would have eight minutes to complete the twelve test trials. After completing the OPT trials or reaching the 8-minute time limit, participants were asked to stop. They then completed the SBSOD, Spatial Anxiety, Exploration Tendency and GPS Dependency and MPT in the given order. The experiment took less than 30 minutes in total and the experimenter debriefed participants orally after they finished.

B. *Results*

The descriptive statistics for each scale are shown in Table 1 and the Pearson correlations are illustrated in Figure 4. The distributions of the absolute errors for OPT and MPT are both positively skewed, which means several participants performed below chance in perspective taking tasks. The skewness and kurtosis for both tasks are higher than 1 which indicates relatively severe departure from normality. To remedy this departure, the data for OPT and MPT were log transformed and the resulting variables were named LOPT and LMPT respectively. Nine participants (5 females and 4 males) did not complete at least one of the perspective-taking tasks within the eight-minute time limitation. However, they all completed more than eight trials out of twelve trials for each task and six of them completed more than ten trials for each ask. Therefore, no strong evidence supports omitting these participants' performance. To examine whether including these participants' performance influences the results or not, all the following tests were conducted twice, with or without these participants' performance. Participants' score on the OPT is calculated based on the

completed trials. Since the results of these analyses did not differ appreciably, the analyses based on all participants' performance are presented here.

Table 1. **Descriptive statistics and Reliability for Study 1**

	Min	Max	Mean	SD	Skewness	Kurtosis	Reliability
GGM	1.0	5.0	3.6	0.9	-0.7	-0.1	0.94
GMN	1.7	5.0	3.4	0.8	-0.3	-0.5	0.94
SBSOD	1.1	6.1	3.8	1.1	-0.3	-0.5	0.90
SA	1.1	4.8	2.7	0.8	0.5	-0.1	0.86
ET	1.3	6.0	3.5	1.1	-0.1	-0.9	0.80
GPS	1.8	5	3.7	0.8	-0.3	-0.6	0.70
OPT	3.9	109.8	31.9	21.9	1.3	1.5	0.80
MPT	6.8	129.6	33.1	23.6	1.6	2.3	0.80
LOPT	1.4	4.7	3.2	0.7	-0.3	-0.3	0.80
LMPT	1.9	4.9	3.3	0.6	0.4	-0.7	0.80

Note: N = 123. GGM: General GrowthMindset; GMN: Growth Mindset in Navigational ability; SBSOD: Santa Barbara Sense-of-direction (self-report sense of direction); SA: spatial anxiety; ET: exploration tendency; GPS: GPS dependence. OPT: Object Perspective Test (Ln(): log transformed mean angular error); MPT: Map Perspective Test (Ln(): log transformed mean angular error); SD: Standard Deviation; Reliability: Cronbach's Alpha

The new scales in this study are Growth Mindset in Navigation Ability (GMN), Exploration Tendency (ET) and GPS Dependency (GPS). The results for these scales are elaborated below.

GMN had high internal reliability (Cronbach's Alpha = 0.94), as did GGM, measuring General Growth Mindset (Cronbach's Alpha = 0.94). Participants' General Growth Mindset (GGM) is significantly correlated to their mindset in navigation ability, $r(122) = .60$, $p < .001$. However, having general growth mindset does not always mean having growth mindset in navigation ability. As shown in Figure 5, 80 out of 123 participants had higher scores on GGM than on GMN while 39 people scored higher on GMN than on GGM (the

remaining 4 participants had the same score on GMN as on GGM.). As shown in Table 1, on average, people are significantly more likely to have a general growth mindset (M = 3.63, SD = .92) than to have growth mindset in navigation ability (M = 3.37, SD = .76), paired t test (122) = 3.71, $p < .001$, d = .308.

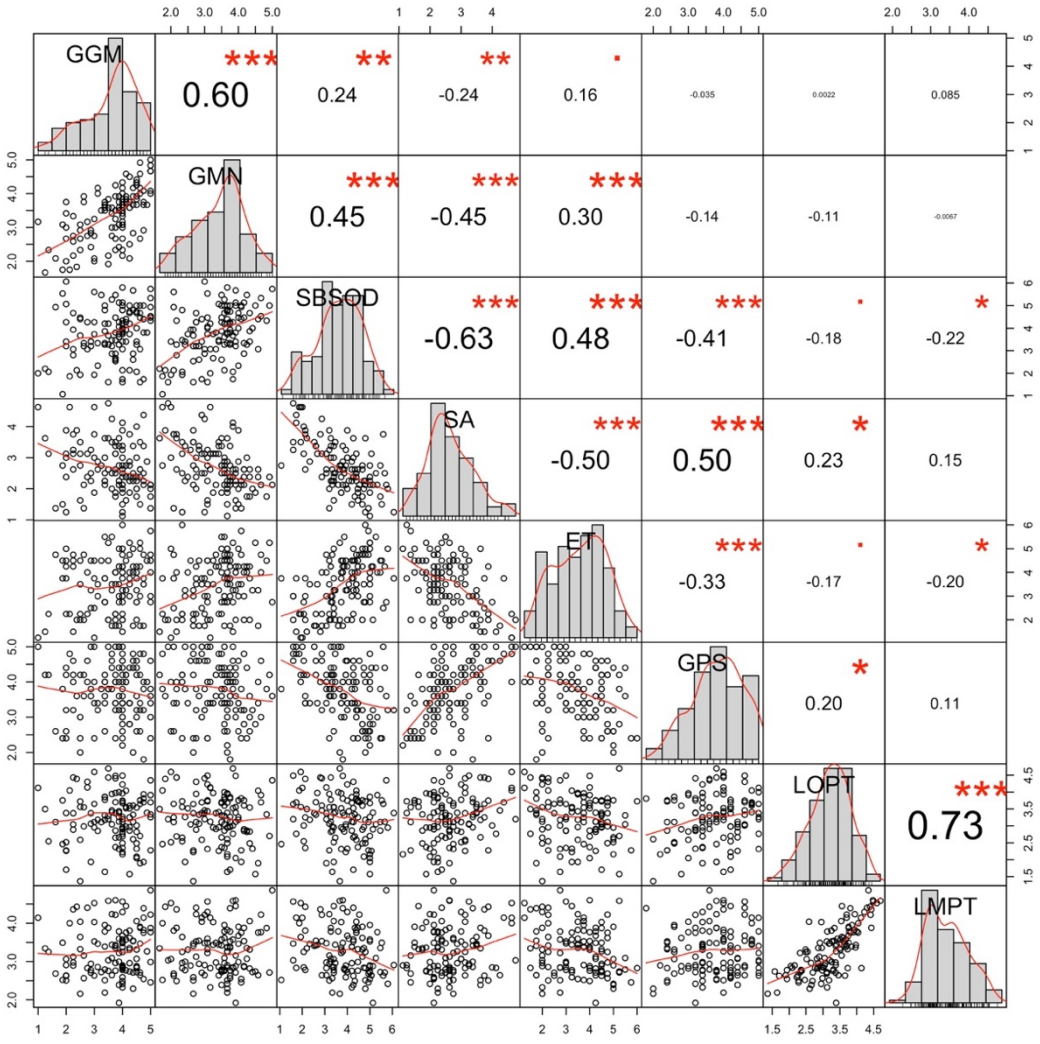

Figure 4. **The Correlations between Variables for Study 1**

*Note:*N = 123. The distribution of each variable is shown on the diagonal. On the bottom of the diagonal: the bivariate scatter plots with a fitted line are displayed. On the top of the diagonal: the value of the correlation plus the significance level as stars. *$p < .05$ **$p < .01$ ***$p < .001$.

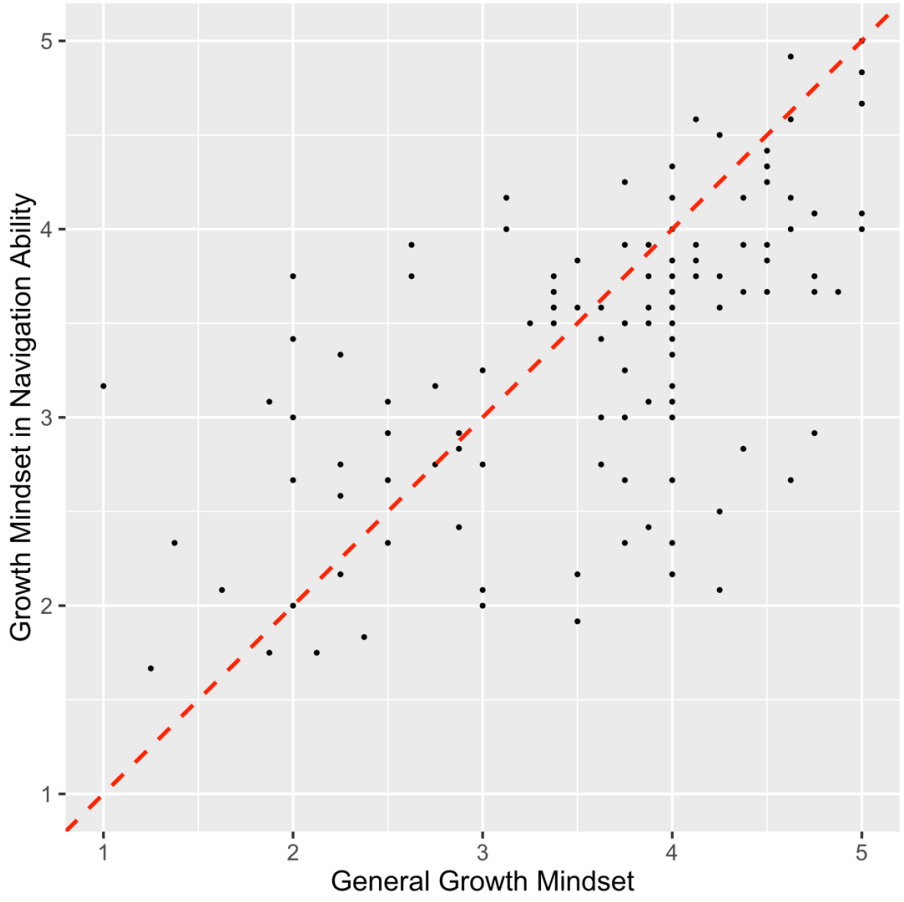

Figure 5. **Scatter plot of General Growth Mindset against GM in Navigation Ability in Study 1**

Note: eighty out of one hundred and twenty-three participants are below the line (GGM = GMN). Thirty-nine out of one hundred and twenty-three participants are above the line. Four participants are on the line.

People with Growth Mindset in Navigation Ability are more likely to report higher SBSOD, $r = .45$, $p < .001$, to report less Spatial Anxiety, $r = -.45$, $p < .001$, and to report higher Exploration Tendency (ET), $r = .30$, $p < .001$. Although General Growth Mindset is significantly correlated with SBSOD and Spatial Anxiety (SA), after controlling for Growth Mindset in Navigation Ability, as shown in Table 2, General Growth Mindset (GGM) is not

significantly associated with SBSOD (partial correlation r = -0.05, p = .61) or SA (partial correlation r = -0.04, p = .63). In contrast, given General Growth Mindset, GMN is still significantly correlated with SBSOD (partial correlation r = 0.39, p < .001) and SA (partial correlation r = -0.39, p < .001). This analysis is stronger evidence that having general growth mindset is partially dissociated from having growth mindset in navigation ability. This result also suggests that people with growth mindset in navigation ability are more likely to have confidence in their navigation ability, less likely to have anxiety during navigation, and are more likely to explore new places.

Table 2. **Partial Correlations in Study 1**

	SBSOD	SA
GGM controlling for GMN	-0.05	0.04
GMN controlling for GGM	0.39***	-0.39***

Note: ***p < .001.

Exploration Tendency (ET) with Cronbach's Alpha 0.80 is a promising indicator which is moderately correlated with SBSOD, SA, GPS Dependency and participants' actual performance in orientation tasks (MPT). That is, people who are more likely to explore different places tend not to rely on GPS, r = -.33, p < .001, and actually tend to have better perspective taking ability (LMPT r = -.20, p = .02 and LOPT r = -.17, p = .07)[1]. However, the observed range for ET is 1.25 to 6, which is narrower than the possible scores 1 to 7, even though it did not depart severely from normality, suggesting that this scale may need revision and more evidence should be collected to support the links between people's exploration tendency and their other navigation abilities and attitudes.

[1] Note that OPT and MPT are error scores so that a higher value indicates less ability.

GPS Dependency also shows links to SBSOD, spatial anxiety and OPT, which suggests that people who are less likely to rely on GPS are more likely to have better performance in orientation tasks. However, the reliability (Cronbach's Alpha = 0.70) of this scale is questionable.

This analysis also verifies SBSOD as a good predictor of navigation ability, replicating previous studies and providing new insights as well. People with a high SBSOD score, which is highly correlated with GMN, $r = .45$, $p < .001$, are less likely to experience anxiety during navigation, $r = -.63$, $p < .001$, more likely to explore different routes, $r = .48$, $p < .001$, and are less likely to rely on GPS, $r = -.41$, $p < .001$. In terms of their actual ability, they tend to have fewer errors on the OPT, $r = -.18$, $p = .05$, [2] and MPT, $r = -.22$, $p = .01$. Since SBSOD is a good indicator of people's navigation ability and shows replicable significant correlations with objective spatial ability measures, more analysis should be conducted in the future to examine how it relates to different attitude measures.

C. *Discussion*

Study 1 revealed some interesting significant associations between people's growth mindset in navigation, exploration tendency, and GPS dependence during navigation. Specifically, people's growth mindset in navigation ability is partially dissociated from their general growth mindset. Also, people with growth mindset in navigation ability tend to have more positive exploration attitudes. Simultaneously, all attitudes about navigation as well as people's actual perspective taking ability are at least marginally significantly correlated with

[2] It is noted that the correlation between LOPT and SBSOD is significant after omitting participants who did not complete tasks, $r = -.19$, $p < .05$.

people's self-report sense of direction (SBSOD) and are negatively correlated with their spatial anxiety.

However, two issues should be further considered before making conclusions. First, the internal reliability and response patterns of the Exploration Tendency and GPS Dependency scales suggest that these scales need more development. Second, the order of the scales in Study 1 is fixed and carry-over effects may cause Growth Mindset scales to set up an initial attitude for participants so that the overall correlations between scales are inflated. Moreover, even if the Pearson correlations (*r*) indicate that the linear relationships between OPT, MPT and Growth Mindset approach 0, one cannot conclude no relationship between performance and spatial tasks. For example, if a training program is applied, participants' improvement from pretest to protests might relate to growth mindset. Also, even if the Pearson correlation (*r*) between SBSOD, Spatial Anxiety and other properties are high, other analysis should be employed to check if these variables explain the same variance (or if there is a latent variable) before making conclusions. More specific models should be built and examined to further understand these relationships after scale revision.

III. Study 2

As noted, one limitation of Study 1 is questionable reliability of the new scales. In Study 2, Exploration Tendency, GPS Dependency, Growth mindset in Navigation Ability and Spatial Anxiety scales were revised based on new published literature (Lyons et al., 2018) and participants' feedback. Also, the order of the questionnaires was randomized to control for carry-over effects. Based on better-developed scales and improved procedures, regression and mediator models were built to examine the associations and dissociations between measures with deeper diagnosis analysis. Correlational analysis was also conducted to replicate the findings of Study 1.

While significant gender differences in many spatial cognition tasks in favor of males consistently emerge (Cashdan & Gaulin, 2016; Hegarty, Montello, Richardson, Ishikawa & Lovelace, 2006; Montello et al., 1999; Silverman & Ealsn, 1992), a more important question is why this pattern is evident. Although gender differences are not a primary focus of the study, discussing gender differences in terms of relative attitudes may potentially provide some insights regarding gender differences in performance. Specifically, it is hypothesized that the gender stereotype about navigation ability is associated with people's mindset about navigation, which may influence their behavior patterns, including exploration tendency and GPS dependence, and consequently, the disadvantaged group may lack enough experience to develop or enhance their navigation ability. Thus, Study 2 took one step towards understanding possible sources of gender differences in navigation ability.

A. Methods

1. Participants

One hundred forty-nine undergraduate students (78 females and 71 males) recruited from the Psychology Subject Pool at the University of California, Santa Barbara participated in this study for course credits.

2. Materials

Study 2 used the same scales for measuring general growth mindset (GMG) and SBSOD (Santa Barbara Sense of Direction). For the scale of Growth Mindset in Navigation Ability (GMN), based on the feedback from prior participants during the debrief phase, the phrase "navigation ability" may not be familiar to some participants, and "sense of direction" is the term used in everyday conversation. Thus, the words related to “navigation ability” were replaced by words related to “sense of direction” in the updated scale (See Appendix A).

Based on the findings of Lyons et al. (2018), five items were added to the Spatial Anxiety Scale and the previous eight items were reworded to make the scale clearer and focus on spatial anxiety during navigation (See Appendix B) instead of including spatial anxiety in other scenarios, such as spatial anxiety during mentally rotating a 3-dimentional structure.

For the scale measuring exploration tendency, four items were added, which are either items with more specific scenarios (e.g., whether trying a new route during traffic congestion) or items related to exploration attitude in a previously developed scale (Pingel, 2010) using items such as "I frequently choose to try new routes when I travel" (See Appendix C).

In terms of the GPS Dependency Scale, one limitation of the version used in Study 1 is that the items share similar scenarios with the Spatial Anxiety Scale, which may inflate the associations between GPS Dependency and Spatial Anxiety or other variables. Also, all items are related to situations where environments are totally new to participants which may cause the scale to have a ceiling effect, indicating that most people rely on GPS when environments are new to them. Four prior items were reworded to make the items distinguishable from the items in Spatial Anxiety Scale. Also four more items related to relatively familiar environments were added, for example, "When returning from a familiar place to my home, if I have never gone home directly from this place before" (See Appendix D).

Finally, in Study 2, only the Objective Perspective Task (OPT) was used to measure participants' perspective taking ability given the high correlation between OPT and MPT found in Study 1. Also, given that the standard time limit for the OPT is 5 minutes, one possible reason that the OPT test was only marginally significantly correlated to SBSOD and Exploration Tendency is that participants were given too much time in Study 1 (8 minutes). In study 2, the standard time limit was used.

3. Procedure

Participants were tested in groups of up to six students per session but working independently. They first completed OPT. After they completed this test or reached the five-minute time limit, they were advanced to six questionnaires and the questionnaires were administrated in a random order set up by the Qualtrics platform.

B. Results

1. Descriptive Statistics and Correlations.

Descriptive Statistics and measures of internal reliability are shown in Table 3. As in Study 1, the distribution of Object Perspective Test (OPT) scores departed from normality. Log-transformed values of OPT were calculated to remedy this departure, creating a new variable LOPT. Thirteen participants (6 females and 7 males) did not complete the OPT within the five-minute time limitation. However, 94.0% of them completed more than ten trials. Therefore, no strong evidence supports omitting these participants' performance. To examine whether including these participants' performance influences the results or not, all the following tests were conducted twice, with or without these participants' data. Participants' score on the OPT is calculated based on the completed trials. Since the results of these analyses did not differ appreciably, the analyses based on all participants' performance are presented here.

Table 3. **Descriptive statistics and Reliability for Study 2**

	Min	Max	Mean	SD	Skewness	Kurtosis	Reliability
GGM	1.0	5.0	3.6	1.0	-0.8	-0.1	0.94
GMN	1.0	5.0	3.1	0.8	-0.1	-0.6	0.94
SBSOD	1.5	6.2	4.0	1.1	-0.2	-0.7	0.88
SA	1.0	4.2	2.5	0.8	0.2	-0.8	0.90
ET	1.3	7.0	3.9	1.1	-0.1	-0.6	0.86
GPS	1.4	4.8	3.5	0.8	-0.4	-0.4	0.81
OPT	4.8	86.4	25.1	17.8	1.5	1.7	0.80
LOPT	1.6	4.5	3.0	0.7	0.1	-0.5	0.80

Note: N = 149. GGM: General Growth Mindset; GMN: Growth Mindset in Navigational ability; SBSOD: Santa Barbara Sense-of-direction (self-report sense of direction); SA: spatial anxiety; ET: exploration tendency; GPS: GPS dependence. OPT: Object Perspective Test (Ln(): log transformed mean angular error); SD: Standard Deviation; Reliability: Cronbach's Alpha

The reliability for the scale of Exploration Tendency (ET), GPS Dependency (GPS) and Spatial Anxiety (SA) are .86, .81 and .90 respectively. These results support the improvement of the scales after revision.

Figure 6 illustrates the distributions for each variable and the Pearson correlations between variables. The association and dissociation between General Growth Mindset and Growth Mindset in Navigation Ability (GMN) were replicated. That is, people who believe their intelligence can be cultivated are more likely to believe their navigation ability can be improved, $r = .42$, $p < .001$. However, on average, people are more likely to have general growth mindset ($M = 3.59$, SD=.97) than to have growth mindset in navigation ability ($M = 3.14$, SD=.81), paired-samples $t(147) = 5.56$, $p < .001$, $d = .50$.

Although Study 2 randomized the order of all questionnaires, the significant links between SBSOD and all the other scales were replicated. Specifically, people with high self-efficacy in navigation (a high SBSOD score) are more likely to believe their navigation ability can be improved, $r = .24$, $p = .002$, feel less anxiety during navigation, $r = -.48$, $p < .001$, are more willing to explore new routes, $r = .56$, $p < .001$, tend to rely less on GPS, $r = -.53$, $p < .001$, and importantly, show better pointing performance in OPT, $r = -.32$, $p < .001$.

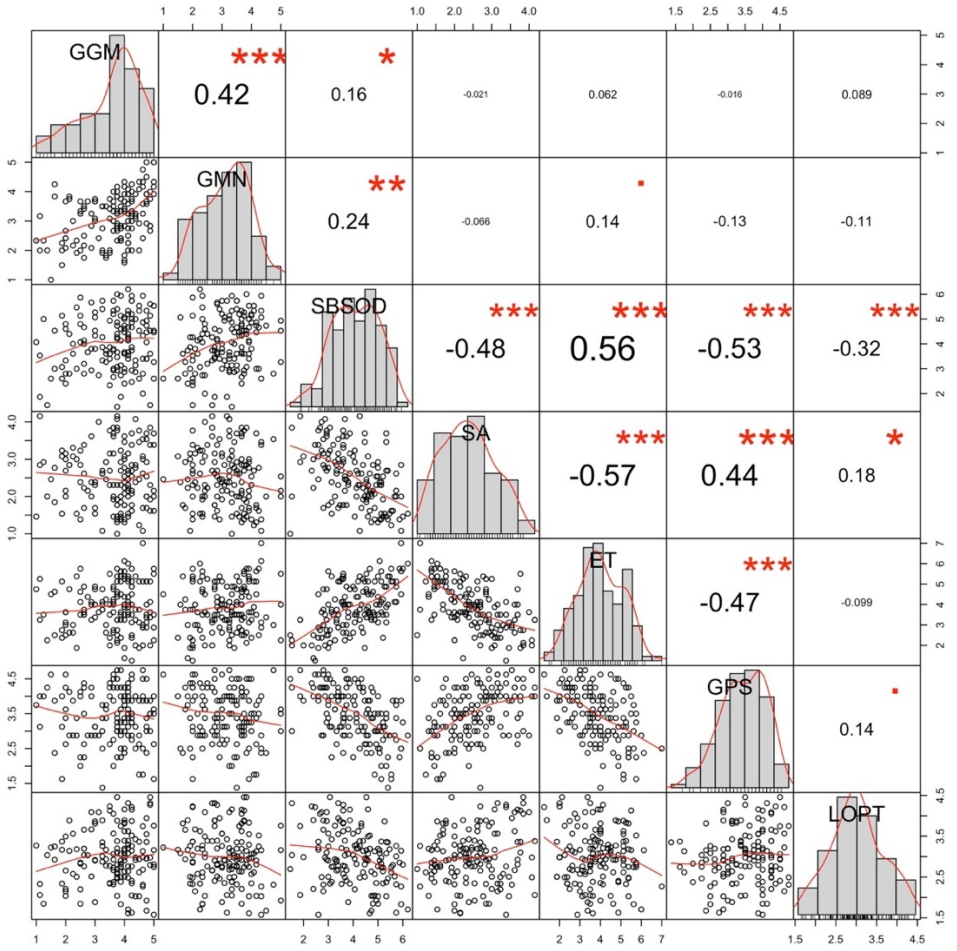

Figure 6. **The Correlations between Variables for Study 2**
*Note:*N = 149. (a) The distribution of each variable is shown on the diagonal. (b) On the bottom of the diagonal: the bivariate scatter plots with a fitted line are displayed. (c) On the top of the diagonal: the value of the correlation plus the significance level as stars. *$p < .05$ **$p < .01$ ***$p < .001$.

Scale revisions improved the reliability of the Exploration Tendency and GPS Dependency scales. These scales now suggest stronger connections between GPS Dependency and Exploration Tendency, $r = -.47$, $p < 0.001$, Spatial Anxiety (SA), $r = -.44$, $p < 0.001$, and SBSOD, $r = -.53$, $p < .001$. The strong associations among SBSOD, SA, ET and GPS Dependency calls for regression models to detect shared variance, which is further examined in the following sub sections.

Participants' perspective taking ability, measured by the error score LOPT, is significantly correlated with SBSOD, $r = -.32$, $p < .001$, Spatial Anxiety, $r = -.18$, $p = 0.03$, and marginally correlated with GPS Dependency, $r = -.18$, $p = 0.09$, based on this administration.

2. Model 1: Multivariate Regression Model

As discussed in Study 1, correlations only reveal the relations which do not control for effects of other variables. Thus, a simultaneous regression analysis was conducted to detect what proportion of variations in SBSOD can be uniquely explained by different variables. Since SBSOD is highly correlated with all variables and evidence supports that it is a good predictor of objective navigation ability in the real world (Hegarty et al., 2002), the SBSOD is treated as the dependent variable in the regression model to infer how other variables are connected to people's actual navigation ability. Four predictor variables were examined: Growth Mindset in Navigation Ability (GMN), Spatial Anxiety (SA), Exploration Tendency (ET) and GPS Dependency (GPS). Together these variables explained 45% of the variance in SBSOD, $R^2 = .45$; $F(4, 143) = 28.63$, $p < .001$. As shown in Table 4, SBSOD was higher for people who reported more tendency to explore their environment, who have growth mindset in navigation ability, who feel less anxiety during navigation, and who are less willing to rely on GPS. An inspection of the standardized partial regression coefficients (β) and squared semi-partial correlations revealed that each of the predictor variables explained a significant amount of unique variance in SBSOD, with Exploration Tendency and GPS Dependency being the stronger predictors. Also, a collinearity check was conducted using the indicator of variance influence factor (VIF). The results demonstrate that there is no severe issue of collinearity. All predictors explain unique variance of the dependent variable

(SBSOD), suggesting that these properties explain unique variance in a person's navigation ability.

Table 4. **Simultaneous Regression Analysis Predicting Self-Report Navigation Ability**

Predictor Variable	b	95% CI for b	β	sr^2	r	VIF
Growth Mindset (in navigation ability)	.205*	[0.038, 0.371]	.15	0.03	.24***	1.024
Spatial Anxiety	-.217*	[-0.434, -0.001]	-.15	0.02	-.48***	1.570
Exploration Tendency	.301***	[0.151, 0.452]	.31	0.06	.56***	1.619
GPS Dependency	-.426***	[-0.634, -0.220]	-.3	0.06	-.53***	1.367

Note: N = 149. b = unstandardized partial regression coefficient; CI= confidence interval; β = standardized partial regression coefficient; sr^2 = squared semi-partial correlation (total variance uniquely explained by the variable). r = zero-order correlation coefficient. *p < .05 **p < .01 ***p < .001. VIF: variance inflation factor. Basically, as long as VIF < 4, the collinearity between covariates is not a severe problem.

3. Model 2: Partial Mediator Model

It is hypothesized that, relative to people with low spatial anxiety, those with high spatial anxiety would be more likely to report poor sense of direction (SBSOD). Furthermore, I predicted that this effect would be mediated by Exploration Tendency (ET) and GPS Dependency (GPS). That is, it is possible that people with high spatial anxiety people would report poor navigation ability because they are less likely to explore different places and are more likely to rely on GPS. Results are summarized in Figure 7. First, people with high spatial anxiety were more likely than people with low spatial anxiety to report a poor sense of direction (SBSOD), b = -0.67, β_c = -0.48, p <.001. Second, people with high spatial anxiety were less willing to explore new routes, b = -0.39, β_{a1} = -0.57, p < .001, and more likely to rely on GPS, b = -0.46, β_{a2} = 0.44, p < .001. Third, when SBSOD was regressed on SA, ET and GPS simultaneously, the results demonstrated that people who are willing to

explore multiple routes are more likely to report high SBSOD, b = 0.32, β_{b1} = 0.33, $p < .001$. Also, people who are more likely to rely on GPS tend to report low SBSOD, b = -0.45, β_{b2} = -0.30, $p < .001$. Importantly, the original association between Spatial Anxiety and SBSOD was reduced when including GPS Dependency and Exploration Tendency as mediators, but remained significant (direct effect: b = -0.21, $\beta_{c'}$ = 0.16, $p = .05$).

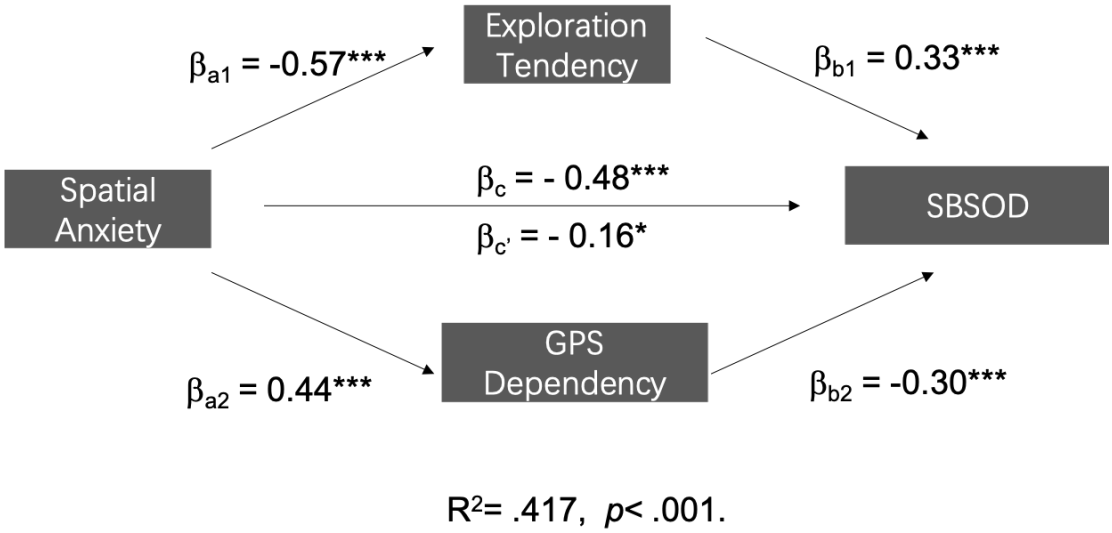

Figure 7. **Summary of the hypothesized mediator model in Study 2.**
Note: N = 149. Path coefficients shown here are standardized regression coefficients(β). Unstandardized coefficients (b) are reported in the text. * $p < .05$. *** $p < .001$.

Nonparametric bootstrapping was conducted to test the significance of the unstandardized indirect effect (IE) of SA on SBSOD as mediated by ET (IE1 = -0.57∗0.33) and GPS (IE2 = 0.44∗-0.30). In this analysis, mediation is significant if the 95% bias corrected and accelerated confidence interval for the indirect effect does not include zero. Results based on 5000 bootstrapped samples revealed that the indirect effect was statistically significant (IE1= -.1854, SEIE1 = .0502, 95%CI = [-.2847, -.0893]; IE1= -.1338, SEIE1 =

.0379, 95%CI = [-.2097, -.0604]), indicating that Exploration Tendency and GPS Dependency partially mediated the relationship between Spatial Anxiety and SBSOD[3].

Given that using observational data to draw causality conclusion faces a potential pitfall of overinterpretation, an alternative model was also built to test the opposite causal direction. Specifically, it is possible that relative to people with high SBSOD, those with low SBSOD would be more likely to report high spatial anxiety. Accordingly, people with low SBSOD will avoid exploring different places and rely on GPS. The results of this alternative model were summarized in Figure 8.

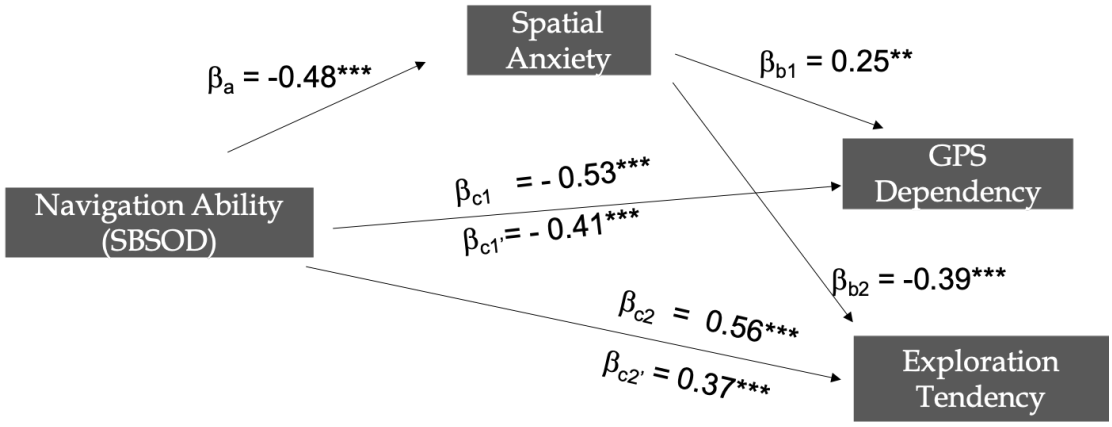

Figure 8. **Summary of an alternative mediator model in Study 2.**
Note: N = 149. Path coefficients shown here are standardized regression coefficients(β). Unstandardized coefficients (b) are reported in the text. * $p < .05$. *** $p < .001$.

First, people with high navigation ability were more likely than people with low navigation ability to report a low GPS Dependency, b = -0.37, β_{c1} = -0.53, $p < .001$ and a high Exploration Tendency, b = 0.58, β_{c2} = 0.56, p <.001. Second, people with high navigation ability were more likely to show low Spatial Anxiety, b = -0.34, β_a = -0.48, p <

[3] Package Psych was used in R to conduct the mediator analysis in this paper

.001. Third, when GPS Dependency and Exploration Tendency were regressed on SA and SBSOD simultaneously, the results demonstrated that people who have high spatial anxiety are more likely to report high GPS Dependency, b = 0.24, β_{b1} = 0.25, p = .002, and low Exploration Tendency, b = -0.57, β_{b2} = -0.39, p < .001. Importantly, the original association between SBSOD and Exploration Tendency as well as GPS Dependency were reduced when including Spatial Anxiety as a mediator, but remained significant (direct effect: b_1 = -0.29, $\beta_{c1'}$ = -0.41, p < .001; b_2 = 0.39, $\beta_{c2'}$ = 0.37, p <.001).

Finally, nonparametric bootstrapping was conducted to test the significance of the unstandardized indirect effect (IE) of SBSOD on GPS as mediated by Spatial Anxiety (IE1 = -0.339∗-0.242) and the unstandardized indirect effect (IE) of SBSOD on ET as mediated by Spatial Anxiety (IE2 = -0.339∗-0.566). In this analysis, mediation is significant if the 95% bias corrected and accelerated confidence interval for the indirect effect does not include zero. Results based on 5000 bootstrapped samples revealed that the indirect effect was statistically significant (IE1 = -.1180, SEIE1 = .0453, 95%CI = [-0.2158, -0.0428]; IE1 = -.1853, SEIE1 = .0509, 95%CI = [-0.2158, -0.0428]), indicating that Spatial Anxiety partially mediated the relationship between SBSOD and Exploration Tendency as well as GPS Dependency.

Taken together, these findings support both directions. People with low spatial anxiety are more likely to have a high score in their navigation ability, and this may be mediated (at least in part) by their greater tendency to explore new routes and less dependency on GPS. Also, people with low confidence in their navigation ability tend to have less tendency to explore new routes and more dependency on GPS, and this may be mediated by their high spatial anxiety.

4. Gender Differences.

Descriptive statistics for men and women are shown in Table 5. Independent sample t-tests (two-tailed) were conducted to detect gender differences in the measures. The results reveal that men are more likely to report high SBSOD, $t(147) = 2.73$, $p = .007$, to report less anxiety, $t(147) = -4.56$, $p < .001$[4], to explore new routes, $t(147) = 2.77$, $p = .006$, and to report lower dependence on GPS, $t(147) = -3.84$, $p < .001$. Also, replicating previous studies in perspective-taking tests, men outperform women in OPT, $t(147) = -4.84$, $p < .001$.

Table 5. **Gender Differences in Study 2**

Variables	Men (Mean)	Women (Mean)	*t*-value	*p*-value
GMN	3.2	3.1	.50	.620
SBSOD	4.3	3.8	2.73	.007
Spatial Anxiety	2.2	2.8	-4.56	<.001
Exploration Tendency	4.1	3.6	2.80	.006
GPS Dependency	3.2	3.7	-3.80	<.001
LOPT	2.7	3.3	-5.18	<.001

Note: N = 149. core Space: Growth Mindset in Navigation ability (GMN): [1,5]; SBSOD:[1,7]; Spatial Anxiety: [1,5]; Exploration Tendency: [1,7]; GPS Dependency: [1,5];

C. Discussion

The reliability of the new scales of Exploration Tendency and GPS Dependency was improved following revision of these scales. The revised Spatial Anxiety Scale, which focuses mainly on spatial anxiety during navigation, was also reliable. The results of the regression model suggest that growth mindset in navigation ability, exploration tendency and GPS Dependency are three promising predictors of a person's navigation ability, at least

[4] The gender differences in SBSOD and spatial anxiety replicated previous research

as measured by self-report. Moreover, Exploration Tendency and GPS Dependency may be treated as important partial mediators of the relationship between anxiety and sense of direction, which suggests that people with high spatial anxiety may have low navigation ability because they are less willing to explore their environment and are more dependent on GPS. However, an alternative model was also supported by the data. That is, people with high navigation ability experience low spatial anxiety so that they are more likely to explore different places and less likely to rely on GPS. More well-controlled experimental studies are called for based on this study in order to advance our understanding of these relationships. For example, we may design a training program, such as a series of workshops, to relieve people's spatial anxiety and introduce growth mindset. By comparing students in the training program with a control group, we may test if changed attitudes can lead to different behaviors and corresponding performance. In addition, the gender differences that emerged in these two new scales may suggest a possible deeper mechanism of social stereotypes in favor of men related to navigation ability.

Moreover, even though the association between general growth mindset and growth mindset in navigation ability (GMN) was replicated, the version of GMN in this study did not show strong associations with other navigation attitude scales, in contrast to the version used in Study 1. There are three possible reasons. First, it is better to use the term "navigation ability" and explain it instead of using the term "sense of direction" because "sense of direction" may only focus on one aspect of navigation ability instead of general navigation ability. Second, in Study 1, the GMN was administered first, whereas, Study 2 used a randomized order of questionnaires. This explanation suggests that Growth Mindset might set up an important attitude about navigation ability and influence the results of

participants' attitude and performance in the following navigational measures in Study 1. Third, the improvement in other scales dissociated the links between GMN and other attitudes so that they explain different variance in a person's navigation attitudes or ability.

Furthermore, according to the multivariate regression model, even though growth mindset is not a strong predictor, the coefficient for the variable (GMN) did not change much after controlling for other factors. That is, it uniquely explained the variance in navigation ability. The main function of growth mindset, according to the literature, is encouraging people to train themselves and approach challenges. That is, the function of growth mindset on achievement is mediated by people's behaviors to target success. Even though we did not detect a direct relation between growth mindset and ET or GPS in two administrations, the mediator model shows that exploration tendency and GPS dependency might be two promising behaviors that mediate the link between spatial anxiety (one important navigation attitude) and navigation ability, measured by SBSOD. One possible reason why growth mindset did not show an effect in this study is that this is not a longitudinal study and growth mindset might show effects if we could give participants a training manipulation. It is hypothesized that people with growth mindset might show improved navigation performance after training.

It is noted that the alternative mediator model is also supported by the data. In other words, the data we have so far cannot rule out the opposite casual direction. That is, people with good navigation ability will explore more places and depend less on GPS than people with poor navigation ability, and these two links are partially due to different levels of spatial anxiety navigators have.

IV. General Discussion

In two studies, three new reliable scales, namely, exploration tendency, GPS dependency and growth mindset in navigation ability, were developed. In addition, the spatial anxiety scale was revised to focus more on navigation instead of general spatial anxiety. The results based on two administrations of these measures demonstrate that people with low spatial anxiety tend to report high exploration tendency and low GPS dependency. These participants also reported high SBSOD and show less error in perspective taking tasks which are two indirect measures of navigation ability.

In terms of the mediation analysis, two possible models were both supported. More evidence to settle the dispute in the future. First, in the hypothesized model, two navigation behavior measures, exploration tendency and GPS dependency, mediate the relation between spatial anxiety and navigation ability. That is, people who have high spatial anxiety might show low navigation ability because they are less likely to explore different places and rely more on GPS, which in turn, impedes their spatial learning processes. This result supports the proposed theoretical mechanism of effects of attitudes on navigation ability. That is, people's attitudes on navigation, especially the emotional dispositions in this model, might influence their navigation behaviors related to spatial learning, and thus result in individual differences in navigation ability. Second, an alternative model shows that people who have good navigation ability initially experience less spatial anxiety so that they explore more places and don't rely on GPS too much.

In terms of motivation dispositions, the multivariate regression analysis suggests that growth mindset is a relatively unique factor which significantly explains the variance of navigation ability. Additionally, based on this model, although spatial anxiety, exploration

tendency and GPS dependency are moderately correlated with each other, they all uniquely and significantly explain variance in SBSOD. These results highlighted an ignored factor in previous studies, namely intrinsic motivation. While the correlations of growth mindset in navigation ability with spatial anxiety and exploration tendency in Study 1 were not replicated as expected in Study 2, this could result from the fact that the effect of intrinsic motivations on navigation is hard to show in a one-time lab experiment or a self-report survey.

These results also provide some insights into studying gender differences in navigation. Except for growth mindset in navigation, all other measures, namely SBSOD, Spatial Anxiety, Exploration Tendency, GPS Dependency and Objects Perspective Task, show significant gender differences. That is men are more likely to report good navigation ability, more tendency to explore, less spatial anxiety, less GPS dependency and have less error in perspective taking. From the perspective of social factors, the stereotype in favor of males in navigation and limits in females' mobility might discourage females' navigational motivations and increase their spatial anxiety (Cashdan & Gaulin, 2016), and consequently impede females' spatial learning processes through the lower exploration tendency and higher GPS dependency. However, it is also possible that the limited navigation ability in some women arouses their spatial anxiety, which facilitates a procedure of adapting more conservative navigation behaviors.

One main limitation of the current work is that the measures used in this study are indirect measures of navigation ability and self-report surveys of attitudes and navigation behaviors. More well-controlled empirical studies, such as training studies, and objective measures, such as virtual environment or real-world navigation tasks, should be used in

future studies. On the other hand, the promising self-report results from our study suggest participants' response processes to these self-report surveys are aligned with their actual attitudes, behaviors, and ability. That is, our results suggest that participants are conscious of the properties and so these properties can be measured by self-report in future.

Another limitation is that the malleability of navigation ability, which is a strong assumption under growth mindset theory, was not been tested. The main way of studying the malleability of navigation ability would be to conduct a training program and to investigate if improved navigation ability can be detected after the training. However, in order to design a training program, researchers need to better understand what experiences or teachable strategies make good navigators outstanding. A main practical implication of this study is that before conducting a training program, setting a growth mindset in navigation ability and relieving spatial anxiety might be preliminary steps in the training program. Also, more active spatial learning processes, including avoiding GPS usage and encouraging exploration should also play an important role in the training program.

Overall the current work took growth mindset into consideration and investigated a possible mechanism underlying the effect of growth mindset and spatial anxiety on navigation ability. The results highlighted how efforts put into navigation behaviors might be a factor influencing individual differences in navigation tasks besides navigators' raw capacity. Also, it is proposed that studying the malleability of navigation ability in the future calls for understanding adaptive navigation attitudes, successful navigation behaviors and effective environmental learning strategies

References

Allen, G. L., Kirasic, K. C., Dobson, S. H., Long, R. G., & Beck, S. (1996). Predicting environmental learning from spatial abilities: An indirect route. *Intelligence*, 22(3), 327-355.

Boone, A. P., Gong, X., & Hegarty., M. (2018). Sex differences in navigation strategy and efficiency. *Memory & Cognition*, 1-14.

Bryant, K. J. (1982). Personality correlates of sense of direction and geographic orientation. *Journal of Personality and Social Psychology*, 43(6), 1318-1324.

Cashdan, E., & Gaulin, S. J. (2016). Why go there? evolution of mobility and spatial cognition in women and men. *Human Nature*, 27(1), 1-15.

Castella, D., Krista, & Byrne, D. (2015). My intelligence may be more malleable than yours: The revised implicit theories of intelligence (self-theory) scale is a better predictor of achievement, motivation, and student disengagement. *European Journal of Psychology of Education*, 30(3), 245-267.

Chrastil, E. R., & Warren, W. H. (2012). Active and passive contributions to spatial learning. *Psychon Bull Rev*,19(1), 1-23. Retrieved from https://doi.org/10.3758/s13423-011-0182-x

Condon, D. M., Wilt, J., Cohen, C. A., Revelle, W., Hegarty, M., & Uttal, D. H.(2015). Sense of direction: General factor saturation and associations with the big-five traits. *Personality and Individual Differences*, 30(86), 38-43.

Dweck, C. (1999). *Essays in Social Psychology. Self-theories: Their Role in Motivation, Personality, and Development.* New York, NY, US: Psychology Press.

Dweck, C. (2006). *Mindset: How We Can Learn to Fulfill our Potential.* New York, NY: Random.

Dweck, C., & Leggett, E. L. (1988). A social-cognitive approach to motivation and personality. *Psychological Review*, 95(2), 256-273. Retrieved from http://dx.doi.org/10.1037/0033-295X.95.2.256

Friedman, A., Kohler, B., Gunalp, P., Boone, A. P., & Hegarty, M.. A computerized spatial orientation test. (Manuscript submitted for publication)

Gagnon, K. T., Thomas, B. J., Munion, A., Creem-Regehr, S. H., Cashdan, E. A. & Stefanucci, J. K. (2018). Not all those who wander are lost: Spatial exploration patterns and their relationship to gender and spatial memory. *Cognition*, 180, 108-117.

Galati, A., Weisberg, S. M., Newcombe, N. S., & Avraamides, M. N. (2018). When gestures show us the way: Co-thought gestures selectively facilitate navigation and spatial memory. *Spatial Cognition and Computation*, 18(1), 1-30. doi:http://dx.doi.org/10.1080/13875868.2017.1332064

Gardony, A. L., Brunye, T. T., & Taylor, H. A. (2015). Navigational aids and spatial memory impairment: the role of divided attention. *Spatial Cognition and Computation*,15(4), 246-284.

Hegarty, M., Burte, H., & Boone, A. P. (2018). Individual differences in large-scale spatial abilities and strategies. In D. R. Montello (Ed.), *Handbook of behavioral and cognitive geography; handbook of behavioral and cognitive geography* (pp. 231-246, Chapter viii, 419 Pages) Edward Elgar Publishing, Northampton, MA.

doi:http://dx.doi.org/10.4337/9781784717544.00022 Retrieved from https://search.proquest.com/docview/2121814010?accountid=14522.

Hegarty, M., Montello, D. R., Richardson, A. E., Ishikawa, T., & Lovelace.h, K. (2006). Spatial abilities at different scales: Individual differences in aptitude-test performance and spatial-layout learning. *Intelligence*, 34(2), 151-176.

Hegarty, M., Richardson, A. E., Montello, D. R., Lovelace, K., & Subbiah, I. (2002). Development of a self-report measure of environmental spatial ability. *Intelligence*, 30(5), 425-447.

Hegarty, M., & Waller, D. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence*, 32(2), 175-191.

Holmes, C. A., Marchette, S. A., & Newcombe, N. S. (2017). Multiple views of space: Continuous visual flow enhances small-scale spatial learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 43(6), 851-861. doi:http://dx.doi.org/10.1037/xlm0000346

Hund, A. M., & Minarik, J. L. (2006). Getting from here to there: Spatial anxiety, wayfinding strategies, direction type, and wayfinding efficiency. *Spatial Cognition and Computation*, 2(3), 179-201.

Hund, A. M., & Padgitt, A. J. (2010). Direction giving and following in the service of wayfinding in a complex indoor environment. *Journal of Environmental Psychology*, 30(4), 553-564.

Ishikawa, T., Fujiwara, H., Imai, O., & Okabe, A. (2008). Wayfinding with a gps-based mobile navigation system: A comparison with maps and direct experience. *Journal of Environmental Psychology*, 28(1), 74-82.

Kozhevnikov, M., & Hegarty, M. (2001). A dissociation between object manipulation spatial ability and spatial orientation ability. *Memory & Cognition*, 29(5), 745-756.

Lawton, C. A. (1994). Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety. *Sex Roles*, 30(11-12), 765-779.

Lawton, C. A., & Kallai, J. (2002). Gender differences in wayfinding strategies and anxiety about wayfinding: A cross-cultural comparison. *Sex Roles*, 47(9-10), 389-401.

Lovden, M., Schaefer, S., Noack, H., Bodammer, N. C., Kuhn, S., Heinze, H.-J., . . .Linden berger, U. (2012). Spatial navigation training protects the hippocampus against age-related changes during early and late adulthood. *Neurobiology of Aging*, 33(3), 620-e9.

Lyons, I. M., Ramirez, G., Maloney, E. A., Rendina, D. N., Levine, S. C., & Beilock, S. L. (2018). Spatial Anxiety: A novel questionnaire with subscales for measuring three aspects of spatial anxiety. *Journal of Numerical Cognition*, 4(3), 526-553.

Montello, D. R. (2005). Navigation. In P. Shah & A. Miyake (Eds.), *The Cambridge Handbook of Visuospatial Thinking* (p. 257–294). Cambridge: Cambridge University Press. doi: 10.1177/0013916593253002.

Montello, D. R., Lovelace, K. L., Golledge, R. G., & Self, C. M. (1999). Sex related differences and similarities in geographic and environmental spatial abilities. *Annals of the Association of American geographers*, 89(3), 515-534.

Münzer, S., & Hölscher, C. (2011). Entwicklung und validierung eines fragebogens zu räumlichen strategien. *Diagnostica*, 57(3), 111-125. doi:http://dx.doi.org/10.1026/0012-1924/a000040

Newcombe, N. S. (2018). Individual variation in human navigation. *Current Biology*, 28(17), R1004-R1008.

Padilla, L. M., Creem-Regehr, S. H., Stefanucci, J. K., & Cashdan, E. A. (2017). Sex differences in virtual navigation influenced by scale and navigation experience. *Psychon Bull Rev*, 24(2), 582-590.

Pazzaglia, F., & Beni, R. D. (2001). Strategies of processing spatial information in survey and landmark-centred individuals. *European Journal of Cognitive Psychology*,13(4), 493-508.

Podsakoff, P. M., MacKenzie, S. B., Lee, J., & Podsakoff, N. P. (2003). Common method biases in behavioral research: A critical review of the literature and recommended remedies. *Journal of Applied Psychology*, 88(5), 879-903. doi:http://dx.doi.org/10.1037/0021-9010.88.5.879

Robins, R. W., & Pals, J. L. (2002). Implicit self-theories in the academic domain: Implications for goal orientation, attributions, affect, and self-esteem change. *Self and Identity*, 1(4), 313-336.

Ruginski, I. T., Creem-Regehr, S. H., Stefanucci, J. K., & Cashdan, E. (2019). Gps-use negatively affects environmental learning through spatial transformation abilities. *Journal of Environmental Psychology*, 64, 12-20.

Silverman, I., & Eals, M. (1992). Sex differences in spatial abilities: Evolutionary theory and data. *In Portions of this paper were presented at the meetings of the International Society for Human Ethology in Binghamton, NY, Jun 1990, the Human Behavior and Evolution Society in Los Angeles, CA, Aug 1990, and the European*

Sociobiological Society in Prague, Czechoslovakia, Aug 1991.. Oxford University Press.

Taylor, S. E., Lerner, J. S., Sherman, D. K., Sage, R. M., & McDowell, N. K. (2003). Portrait of the self-enhancer: Well adjusted and well liked or maladjusted and friendless? *Journal of Personality and Social Psychology*, 84(1), 165-176. doi:http://dx.doi.org/10.1037/0022-3514.84.1.165

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological Review*, 55(4), 189-208. doi:http://dx.doi.org/10.1037/h0061626

Tourangeau, R., Rips, L. J., & Rasinski, K. (2000). The psychology of survey response. Cambridge University Press, New York, NY. doi:http://dx.doi.org/10.1017/CBO9780511819322 Retrieved from https://search.proquest.com/docview/619456575?accountid=14522

Uttal, D. H., & Cohen, C. A. (2012). Spatial thinking and stem education: When, why, and how? *In Psychology of Learning and Motivation*, 57, 147-181.

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin*, 139(2), 352-402. doi:http://dx.doi.org/10.1037/a0028446

Weisberg, S. M., & Newcombe, N. S. (2018). Cognitive maps: Some people make them, some people struggle. *Current Directions in Psychological Science*, 27(4), 220-226. doi:http://dx.doi.org/10.1177/0963721417744521

Weisberg, S. M., & Newcombe, N. S. (2016). How do (some) people make a cognitive map? routes, places, and working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 42(5), 768-785. doi:http://dx.doi.org/10.1037/xlm0000200

Weisberg, S. M., Schinazi, V. R., Newcombe, N. S., Shipley, T. F., & Epstein, R. A. (2014). Variations in cognitive maps: Understanding individual differences in navigation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 40(3), 669-682. doi:http://dx.doi.org/10.1037/a0035261

Woollett, K., Spiers, H. J., & Maguire, E. A. (2009). Talent in the taxi a model system for exploring expertise. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 364(1522), 1407-1416.

Appendix A

Growth Mindset in Navigation Ability

Right before giving participants Growth Mindset in Navigation Ability, instructions were given to explain the definition of navigation ability (in Study 1) or Sense of direction (in Study 2) and the following question (in Study 1) was used to check participants' understanding. Participants could not move on to the scale if they got the question wrong.

The instructions in Study 1. "Navigation ability is the ability to maintain a sense of direction and location while moving about in the environment and ability to complete tasks like giving directions, judging distances between places, developing a mental map for a new environment, finding the quickest way to reach a place, and orienting in unfamiliar places."

The Checking Question. "Based on this description, please mark which items belong to navigation ability: (a) Solving math problems; (b)Describing a pathway to someone; (c) Building or repairing something; (d) Orienting in unfamiliar places; (e) Feeling one's emotions; (f) Paying attention during a lecture; (g) Engaging in a new sport; (h) Finding the quickest way to reach a place;"

The instructions in Study 2."Your sense of direction refers to your ability to navigate, to maintain a sense of your orientation and location during navigation and your ability to complete tasks like giving directions, learning the layout of new environments, finding the quickest way to reach a place, and orienting in unfamiliar places."

Items. Using the scale below, please indicate the extent to which you agree or disagree with the following statements (the order random in Study 2):

1. I have a certain amount of navigation ability (sense of direction), and I can't really do much to change it.

2. My navigation ability (sense of direction) is something about me that I can't change very much.
3. To be honest, I can't really change how good I am at tasks related to navigation ability (sense of direction).
4. I can gradually get familiar with a new environment, but I can't really change my basic navigation ability (sense of direction).
5. No matter who I am, I can significantly change my navigation ability (sense of direction).
6. I can always substantially change how good I am at navigating (using my sense of direction).
7. No matter how much navigation ability (good sense of direction) I have I can always change it quite a bit.
8. I can change even my basic navigation ability (sense of direction) considerably.

Appendix B

Spatial Anxiety

Please rate your level of anxiety on a 5-point scale in the following scenarios.

1. Leaving a store that you have been to for the first time and deciding way to turn to get to a destination.
2. Finding your way out of a complex arrangement of offices that you have visited for the first time.
3. Pointing in the direction of a place outside that someone wants to get to and has asked you for directions when you are in a windowless room.
4. Locating your car in a very large parking lot or parking garage.
5. Trying a new route that you think will be a shortcut without the benefits of a map.
6. Finding your way back to a familiar area after realizing you have made a wrong turn and become lost while traveling.
7. Finding your way around in an unfamiliar mall.
8. Finding your way to an appointment in an area if a city or town with which you are not familiar
9. Finding your way back to your hotel after becoming lost in a new city.
10. Asked to follow directions to a location across town without the use of a map
11. Trying to get somewhere you have never been to before in the middle of an unfamiliar city
12. Asked to do the navigation planning for a long car trip.
13. Memorizing routes and landmarks on a map for an upcoming exam.

Note that item 9-13 were only used in Study 2 and item order was random in Study 2.

Appendix C

Exploration Tendency

Using the scale below, please indicate the extent to which you agree or disagree with the following statements:

1. When I have a chance, I like to explore different routes to get to my destination.
2. When I have a chance, I like to try a new route that I think will be a shortcut to my destination.
3. I prefer to follow my daily route or the way I have gone before to get to my destination.
4. I prefer to plan and take a specific route to my destination instead of exploring a new way using my sense of direction.
5. I prefer to try to find a detour rather than sitting in traffic, even if I'm not quite sure I can find a faster way.
6. I frequently choose to try new routes when I travel.
7. If I already know a route to get to my destination, I don't think it is important to find new routes in the environment.
8. I don't like to take a new route unless I have a friend with a good sense of direction guiding me.

Note that item 5-8 were only used in Study 2. The item order was random in Study 2.

Appendix D

Global Positioning System Dependency

Please respond how much you RELY ON the benefits of a GPS in the following situation. (In these questions, unfamiliar means you have traveled less than twice before in the situation described below.)

Study 1	Study 2 (The item order was random)
1. Deciding which direction to walk in an un-familiar city or town after coming out of a train/bus/metro station. 2. Finding my way to an appointment in an unfamiliar area of a city or town. 3. Leaving a store that I have been to for the first time and deciding which way to turn to get to a destination. 4. Finding my way back to a familiar area after realizing I have made a wrong turn and become lost while traveling. 5. Pointing in the direction of a place out-side that someone wants to get to and has asked for directions when I am in a window-less room.	1. Deciding which direction to walk in an un-familiar city or town after coming out of a train/bus/metro station. 2. Finding my way to an appointment in an unfamiliar area of a city or town. 3. Leaving a store that I have been to for a couple of times and deciding which way to turn to get to a destination. 4. Finding my way back to a familiar area after realizing I have made a wrong turn. 5. Returning from a familiar place to my home, if I have never gone home directly from this place before. 6. Taking a novel detour to a familiar place, due to a roadblock on my usual route. 7. Finding my way to an appointment in an area of a city or town with which I am only roughly familiar. 8. Traveling to a new place after getting someone's directions.