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How anxiety and growth mindset are linked to navigation ability: Impacts of exploration and GPS use

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ABSTRACT

There are large individual differences in navigation ability, but we know little about the causes of these differences. Here, we examine how motivational and emotional dispositions affect every-day navigation and in turn influence navigation ability. We developed three new self-report surveys, measuring growth mindset in regard to navigation ability, tendency to explore new places, and tendency to rely on Global Positioning Systems (GPS) during navigation. In Study 1 (N = 123) we developed initial measures and in Study 2 (N = 150) we refined these measures and developed mediation models to test how motivational and emotional dispositions affect human navigation. Findings indicated that people with low spatial anxiety tend to explore their environments more and rely less on GPS during navigation. Moreover, these navigation behaviors partially mediate the relationship between anxiety and self-reported navigation ability. Growth mindset in navigation ability (a belief that one's navigation ability can be improved) explains a unique portion of variance in self-reported navigation ability, suggesting that growth mindset may motivate people to seek out navigation challenges and train themselves to be more effective navigators in daily life. This study paves a new path for understanding how motivational and emotional dispositions affect the development of navigation ability and provides insights for future navigation training programs. The new self-report surveys and a revised Spatial Anxiety Survey are available on the Open Science Framework website.

1. Introduction

1.1. Overview

Navigation ability, also referred to as environmental spatial ability, is essential in daily life. We rely on navigation ability to maintain a sense of orientation and location as we travel, to learn the layout of new environments, and to plan routes to goal locations in familiar environments. Recent studies have documented large individual differences in navigation ability (e.g., Ishikawa & Montello, 2006; Weisberg & Newcombe, 2018) but we know little about why some people are more able navigators than others, and studies to date have focused primarily on cognitive correlates of navigation ability, including spatial and other cognitive abilities (Hegarty, Montello, Richardson, Ishikawa & Lovelace, 2006). Successful navigation requires multiple cognitive processes, including spatial learning, spatial updating, and decision making, so it has been suggested that developing navigation ability requires effort (Weisberg & Newcombe, 2018). This suggests that the development of good navigation might not depend on ability alone but might also depend on motivation and emotion. However, the effects of motivation and emotion on navigation ability are understudied. The current study aims to fill a gap in our knowledge by studying how emotional and motivational dispositions affect people's everyday navigation behaviors and consequently, how their navigation experiences might affect navigation ability. It also contributes new measures of these constructs.

1.2. Motivational dispositions

In studies of motivation, the most basic distinction is between intrinsic and extrinsic motivation. Intrinsic motivation refers to inherent drives due to interest or enjoyment. Extrinsic motivation refers to external incentives for achieving a certain goal (Ryan & Deci, 2000). In a recent study, Weisberg and Newcombe (2016) investigated the effect of a monetary incentive on participants' accuracy in learning the layout of a desktop virtual environment (Virtual Silcton). Monetary incentive (an extrinsic motivator) had no effect on layout learning. However, this does not preclude effects of intrinsic motivators, such as mastery-oriented or learning goals (i.e., aiming to improve ability) (Taylor, Lerner, Sherman,

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Sage, & McDowell, 2003). Here, we study the effect of intrinsic motivation on everyday navigation behaviors and begin to study its effect on navigation ability. Specifically, we propose that a growth mindset, or the belief that one can improve one's navigation ability, motivates people to seek out navigation challenges so that they explore their environments more and consequently develop better navigation abilities.

1.3. Emotional dispositions

Emotional dispositions may also affect navigation strategies in daily life and consequently influence navigation performance. One important emotional disposition that can affect navigation is spatial anxiety (Cashdan & Gaulin, 2016; Pazzaglia, Meneghetti, & Ronconi, 2018). In an early paper, Lawton (1994) found that high spatial anxiety was linked to use of route strategies in contrast to orientation strategies during navigation. A route, or response strategy, refers to navigating by following well known routes which consist of a sequence of landmarks, turns, or intersections from a first-person (egocentric) perspective. An orientation strategy, which is sometimes called a survey or place strategy, refers to using an allocentric representation of the layout of the environment in the mind to maintain orientation during travel and take novel routes to goal locations (Hund & Padgitt, 2010; Münzer & Hölscher, 2011; Pazzaglia & Beni, 2001; Tolman, 1948). Spatial anxiety is also associated with less efficient navigation and more navigation errors (Hund & Minarik, 2006), although the direction of causality underlying these associations is unclear. It is possible that anxiety impedes successful navigation, but it is also possible that people become spatially anxious because they are aware of their navigation errors (Weisberg & Newcombe, 2018).

1.4. Growth mindset and navigation ability

Inspired by mindset theory, we aim to establish a conceptual framework that links motivational and emotional dispositions to navigation ability with navigation behaviors as mediators. A growth mindset refers to the belief that one can improve some ability (such as intelligence). A growth mindset can be contrasted with a fixed mindset, that one's ability is not malleable (Dweck, 2006). Research on mindset theory over the past three decades shows that a single belief regarding the malleability of intelligence leads to a series of subsequent motivations and actions, serving as the core of people's meaning systems, which influence individual achievement (Castella, Krista, & Byrne, 2015; Dweck, 1999; Dweck & Leggett, 1988; Dweck & Yeager, 2019). The proposed mechanism is that people with growth mindsets are more likely to value effort and approach challenges to achieve their learning goals, even if they are anxious (Dweck & Leggett, 1988). These dispositions and behaviors eventually lead them to higher levels of achievement than people with fixed mindsets, who do not believe that their abilities can be improved. People with fixed mindsets are more likely to withdraw from challenges and show other helpless behavior patterns.

Mindset theory has been shown to function not only in school settings (Robins & Pals, 2002), but also in parenting, business, organization management, and intimate relationships (Dweck, 2006). However, no previous research has investigated how growth mindset influences navigation ability, even though there has been much discussion of the malleability of spatial abilities in recent years (Uttal & Cohen, 2012; Uttal et al., 2013). Applying mindset theory to navigation, we propose that people with different mindsets treat navigational challenges differently. We suggest that people with growth mindsets seek out navigation challenges by actively exploring their environment. In contrast, we propose that people with fixed mindsets withdraw from navigation challenges and one way of doing this, given current technology, is to rely more on GPS technologies. Thus, eventually, people with growth mindsets become better at navigation because they get more practice at navigation skills.

1.5. Navigation behaviors

As mentioned in the previous section, two everyday navigation behaviors highlighted in the present study are exploration and GPS use. These behaviors may mediate the relation between spatial anxiety, growth mindset and navigation performance. Spatial anxiety may be initiated by navigation failures, but more importantly, these failures may prevent people from actively exploring their environment in daily life, so that they do not develop sufficient navigation ability. In contrast, people who do not experience spatial anxiety may explore their environments more, therefore developing more navigation ability.

The first researcher to highlight how navigation behaviors may influence spatial knowledge acquisition was Bryant (1982), who studied the relationship between personality and self-reported sense of direction. Bryant proposed that engagement with spatial environments 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 operationalize engagement or test this prediction directly. In related research, Meneghetti and colleagues found that a self-assessed trait labelled "pleasure in exploring new places" is positively related to self-reported sense of direction, ability to point to cardinal directions, and finding shortcuts in a known environment (Meneghetti, Borella, Patore & De Beni, 2014; Pazzaglia, Meneghetti, Labate, & Ronconi, 2017; Pazzaglia et al., 2018). Moreover, other studies have linked personality factors such as openness (adventurousness), and extraversion (energy and approach behavior) to self-reported sense of direction (Condon et al., 2015), and pleasure in exploring new places (Meneghetti, Borella, Pastore, & De Beni, 2014; Pazzaglia et al., 2017; 2018). These studies suggest a relation between personality traits, exploration and navigation ability, but do not conceptualize exploration as a behavioral measure, as we do in the present study. They conceptualize it as an emotional or other personal trait. Also, they do not propose a cognitive mechanism underlying the effect of exploration.

Other studies, focusing on cognitive mechanisms, have revealed connections between exploration and navigation performance via active learning, adding support to the idea that one way of developing navigation ability is to challenge oneself to perform navigation tasks. Navigation ability can be improved or preserved by practice (Lovden et al., 2012; Woollett, Spiers, & Maguire, 2009; McLaren-Gradinaru et al., 2020). Moreover, Gagnon et al. (2018) found that navigators who explored a larger range of a new environment (i.e., diffused through the space more quickly) gained better survey knowledge of the environment (as measured by a pointing task) than those who explored the environment less. Chrastil and Warren (2012) found that navigators who learned by actively walking through an environment constructed more accurate survey knowledge compared to navigators who learned a new environment passively (by watching a navigation video). These studies suggest that if people explore more, such that they actively build representations of their environment, their performance in navigation tasks is better. However, in previous research, researchers did not explicitly link exploration to motivational or emotional dispositions.

With the advent of Global Positioning Systems (GPS), accessible on mobile phones and in cars, people can now avoid the need to explore or develop internal representations of their environment by relying on the navigation instructions provided by these systems. We propose that people with high spatial anxiety and fixed mindsets may depend more on these systems, and consequently may be less likely to develop navigation ability through daily experience. In support of this proposal, previous research has established that use of GPS technologies is associated with less spatial knowledge acquisition. Ishikawa, Fujiwara, Imai, and Okabe (2008) compared participants' navigation behaviors and spatial knowledge after they learned an environment either by using GPS, paper-maps, or from direct-experience. Compared with paper-map users and direct-experience navigators, GPS users had poorer performance across measures of navigation, including more stops during navigation, slower travel, greater direction estimation errors and less accurate sketch maps. Using dual-task methodology to study the effect of GPS on navigation, Gardony, Brunye, and Taylor (2015) postulated that following GPS while navigating inhibited participants' spatial learning due to divided attention. Ruginski, Creem-Regehr, Stefanucci, and Cashdan (2019) developed mediation models suggesting that differences in spatial abilities, such as perspective taking and mental rotation ability, mediate the effects of GPS use on environmental learning. Cross-sectional and longitudinal studies also indicate that habitual GPS use negatively influences navigation ability, but self-reported sense of direction does not influence GPS use (Dahmani & Bohbot, 2020). In addition, a recent study showed that people with different personality traits show different navigational aid preferences (Meneghetti, Grimaldi, Nuccio & Pazzaglia, 2020). However, no previous research has asked how mindsets and spatial anxiety affect GPS use.

1.6. Present studies

In the present studies we developed and tested a conceptual mediation model, illustrated in Fig. 1, proposing that everyday behaviors, namely exploration and GPS use, mediate the relationships between mindsets, spatial anxiety and navigation ability. We proposed that a growth mindset and low spatial anxiety would be associated with exploration whereas a fixed mindset and high spatial anxiety would be associated with GPS use. Based on previous studies (Ishikawa et al., 2008; Gardony et al., 2015; Ruginski et al., 2019; Meneghetti et al., 2014), we hypothesized that exploration would be associated with good navigation ability, because exploration gives people opportunities to form flexible and accurate spatial representations. In contrast we hypothesized that GPS use would be associated with poor navigation ability because GPS use inhibits spatial learning (cf. Gardony et al., 2015).

The present studies address the following questions:

1. What are the associations between people's navigation dispositions, navigation behaviors, and ability?
2. Do navigation behaviors, namely exploration and GPS use, mediate the relationship between navigation dispositions and navigation ability, as shown in Fig. 1.

In the current studies, navigation ability was indirectly measured by a self-report questionnaire, the Santa Barbara Sense of Direction scale (SBSOD; Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002). Navigation is a multidimensional ability (Montello, 2005; Pazzaglia et al., 2018; Weisberg & Newcombe, 2018; Wolbers & Hegarty, 2010), which includes the ability to learn the layout of new environments, to maintain a sense of location and orientation while one moves through the environment, and the ability to plan routes to goal locations. While using a self-report survey as an ability measure is not ideal, self-reported

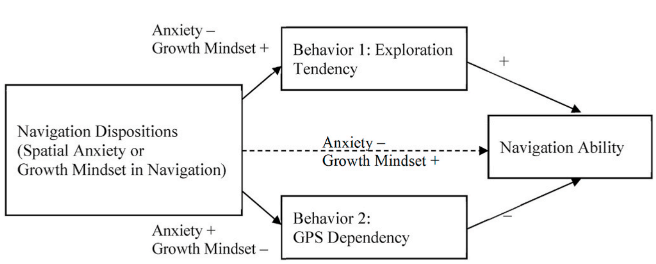

Fig. 1. The Conceptual Mediator Model Driving the Research Questions of the Current Study. Positive (+) and negative (−) signs above each path coefficient indicate the predicted direction of association for each variable pair relationship. High spatial anxiety is expected to be associated with less navigation ability but high growth mindset in navigation is expected to be associated with more navigation ability. It is expected that people's navigation behaviors, namely, low exploration tendency and high GPS dependency will serve as mediators between people's navigation dispositions and navigation abilities.

sense of direction has the advantages that it is related to most aspects of navigation ability and has been used in many previous studies of individual differences in navigation (e.g. Bryant, 1982; Meneghetti et al., 2014; Pazzaglia et al., 2017). Although the SBSOD is referred to as a "sense of direction" scale, it does not just measure people's ability to judge the directions to locations in the environment. For example, some sample items are about route navigation ("I can usually remember a new route after I have traveled it only once"). Hegarty et al. (2002), established the validity of this scale by finding that it correlated with learning spatial layout, pointing to locations in a familiar environment, and spatial updating. Since then, a growing number of studies has added evidence that SBSOD score is significantly correlated with other navigation tasks, including route-based as well as survey based tasks (Donald Heth, Cornell, & Flood, 2002; Epstein, Higgins, & Thompson-Schill, 2005; Hegarty, Burte, & Boone, 2018; Hund & Padgitt, 2010). Thus, using the SBSOD to measure navigation ability is a promising starting point for understanding how motivational and emotional factors are related to navigation ability.

In addition to using this self-report measure, two perspective taking tasks (Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001; Montello, Lovelace, Golledge, & Self, 1999) were employed here as preliminary objective evidence of differences in large-scale spatial abilities. Perspective taking ability is partially dissociated from small scale spatial visualization ability (e.g., as measured by mental rotation tasks) and is more related to 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; Weisberg, Schinazi, Newcombe, Shipley, & Epstein, 2014). Perspective taking ability is also an important mediator of the relationship between small-scale spatial ability and navigation ability (Allen, Kirasic, Dobson, Long, & Beck, 1996).

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 to examine the correlations between these measures. Based on the results of Study 1, these scales were further developed in Study 2. Importantly, in Study 2, regression and mediation analyses were used to investigate the effects of motivational and emotional dispositions on navigation ability and test the proposed mediation models.

2. Study 1

2.1. Methods

2.1.1. Participants

One hundred twenty-three undergraduate students (74 females and 49 males) participated in this study in return for course credit. An a priori power analysis, conducted using GPower3.1 (Erdfelder, Faul, & Buchner, 1996), indicated one hundred and nine is the minimum number of participants required to detect a medium sized correlation of 0.3 with a power of .90 and an alpha of .05, two tailed.

2.1.2. Materials

The following questionnaires were administered on the Qualtrics online survey platform.

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 rewords 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. Possible scores range from 1 to 5 where a higher score indicates more of a general growth mindset. Research to date shows that this scale has good internal consistency, α = 0.90.

Measure of Growth Mindset in Navigation Ability. The measure of growth mindset in navigation ability was based on the scale for general growth mindset (Castella et al., 2015). To create this scale, in each item of the original scale, the word "intelligence" was replaced by the words "navigation ability" (e.g. "I believe I can always substantially improve my intelligence level," became "I believe I can always substantially improve my navigation ability."). In addition, the new 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 to that of the GGM scale (4 items are reverse scored). A higher score indicates more of a 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.

To make sure that participants understood the meaning of "navigation ability", they were given the following instructions: "Navigation ability is the ability to maintain a sense of direction and location while moving about in the environment and the 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 instructions were followed by the following question and participants were not allowed to move on to the survey unless they answered this question correctly:

"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 an 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."[1]

Measure of Self-Reported Navigation Ability. The Santa Barbara Sense of Direction Scale was employed to measure participants' navigation ability (Hegarty et al., 2002). 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 score indicates a better sense of direction. Previous research (Hegarty et al., 2002) has shown that the internal reliability of the scale is 0.88.

Measure of Spatial Anxiety. Lawton's Spatial Anxiety Scale (Lawton, 1994) was employed to measure spatial anxiety. In this scale, participants are asked to rate the level of spatial anxiety that they 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 to rate their anxiety in these situations. The average of the eight items was used as the measure of spatial anxiety. The potential scores range from 1 to 5, and a higher score indicates more anxiety.

Measure of Exploration Tendency. A new scale was developed to measure a person's tendency to explore environments. 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 to rate their agreement with these statements. A higher score indicates that participants are more likely to explore environments.

Measure of Global Positioning System Dependency. The measure of Global Positioning System (GPS) Dependence was based on 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 the eight different scenarios used in the Spatial Anxiety scale. The potential scores range from 1 to 5, and a higher average score indicates that participants are more likely to use GPS applications during navigation.

Measure of Perspective-Taking ability. Perspective-taking ability was measured by two computer-based tasks, a revised version of the Object Perspective Test (OPT; (Friedman, Kohler, Gunalp, Boone, & Hegarty, 2020) and a revised version of the Map Perspective Test (MPT) (Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001; Montello et al., 1999). The tasks were programmed in Eprime (PST Software) and the trials were presented on ASUS generic monitors with a 1920 × 1080 resolution. In the revised Object Perspective Test, an array of seven non-directional objects was used as the stimulus (See Fig. 2). For each of the 12 randomly ordered items, the participant was asked to imagine being at an object, facing another object and to indicate the direction to a third object using an arrow circle. The score on the test was the average angular error across items. The Map Perspective Test (MPT) shares similar instructions, implementation, and score rules with the OPT, except that participants need to estimate directions based on a fictitious map (See Fig. 3) and the twelve items were represented in a fixed order.

2.1.3. Procedure

The local Institutional Review Board (IRB) reviewed and approved the study as adhering to ethical guidelines. 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. After signing a consent form, participants completed the questionnaires measuring general growth mindset and growth mindset in navigation ability without a time limit. Following these two questionnaires, the Object Perspective Test (OPT) was administered including the instructions and three practice trials, and participants were given 8 min to complete the twelve test trials. After completing the OPT trials or reaching the 8-min time limit, participants were asked to stop. They then completed the SBSOD, Spatial Anxiety, Exploration Tendency, GPS Dependency questionnaires and MPT in that order. The study took less than 30 min in total.

2.2. Results

The descriptive statistics for each measure are shown in Table 1 and the Pearson correlations between the measures are shown in Table 2. The distributions of the angular errors for OPT and MPT were both positively skewed, and several participants had angular errors above chance level.[2] To remedy this departure from normality, the data for OPT and MPT were log transformed and the resulting variables were named LOPT and LMPT respectively and used in the correlational analyses.[3]

Growth Mindset in Navigation Ability (GMN) had high internal reliability, as did General Growth Mindset (GGM) (see Table 1).

[1] The correct answers are b, d and h.

[2] Angular error can range from 0 to 180°, so the chance performance is defined as 90°. Above chance angular error means error is larger than 90°.

[3] Nine participants (5 females and 4 males) did not complete at least one of the perspective-taking trials within the 8-min 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 task. Therefore, no strong evidence supports omitting these participants' performance. To examine whether including these participants' performance influences the results, 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.

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

[5] It is noted that the correlation between LOPT and SBSOD is significant after omitting participants who did not complete tasks, $r = -0.19$, $p < .05$.

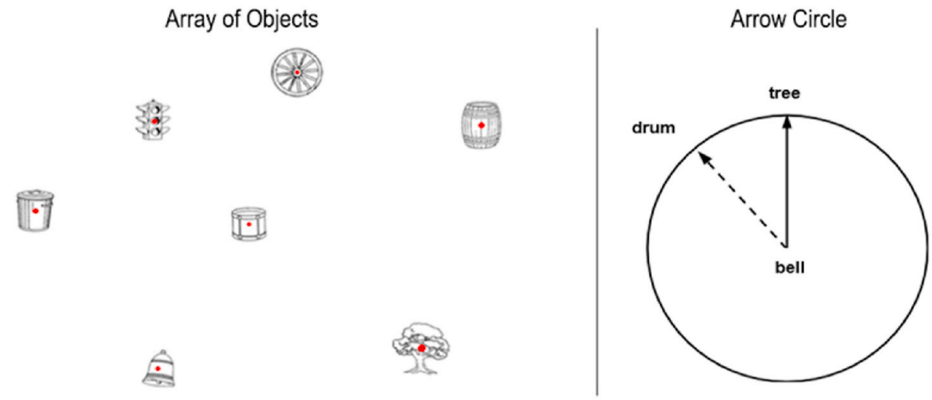

Fig. 2. A Sample Trial of the Object Perspective Test (Friedman et al., 2020). The dash line indicates the correct answer. In each trial no dash line shows up. Participants clicked the arrow circle to initiate the second line pointing to a direction and drag the line until participants are confident that the second line is pointing to the direction they are required to indicate.

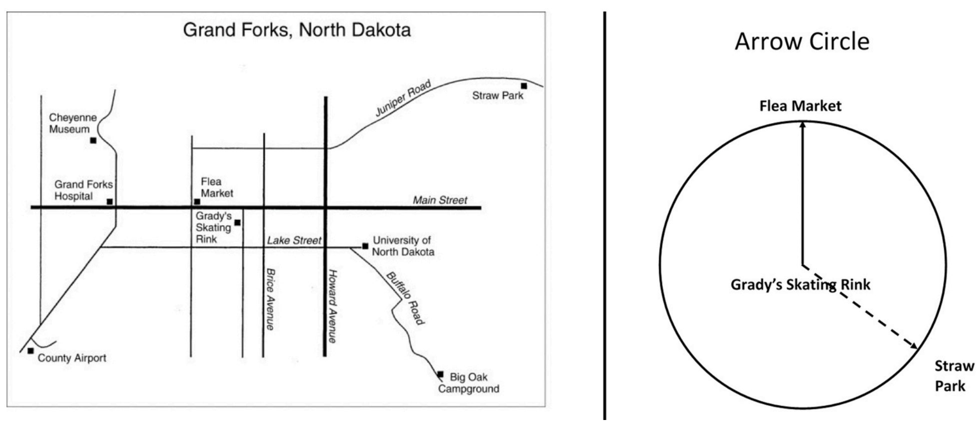

Fig. 3. A Sample Trial of the Map Perspective Test. This task is based on a fictitious map of Grand Forks (Montello et al., 1999). The dash line indicates the correct answer. In each trial no dash line (correct answer) shows up. Participants clicked the arrow circle to initiate a second line pointing 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.

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	5.0	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 (LOPT: log transformed mean angular error); MPT: Map Perspective Test (LMPT: log transformed mean angular error); SD: Standard Deviation; Reliability: Cronbach's Alpha.

Participants' General Growth Mindset (GGM) is significantly correlated with Growth Mindset in Navigation Ability, r (122) = 0.60, $p < .001$. However, as shown in Table 1, on average, people have higher General Growth Mindset than Growth Mindset in Navigation Ability, paired t (122) = 3.71, $p < .001$, $d = 0.31$, 95% CI is [0.12, 0.39]. This suggests that people treat general intelligence and navigation ability differently such that they are more likely to believe navigation ability is fixed compared to general intelligence.

People with growth mindset in navigation ability were more likely to report a better sense of direction (SBSOD), $r = .45$, $p < .001$, less Spatial Anxiety, $r = -.45$, $p < .001$, and higher Exploration Tendency (ET), $r = .30$, $p < .001$. Although General Growth Mindset is significantly correlated with SBSOD and Spatial Anxiety (SA), its correlations with these variables are no longer significant after controlling for Growth Mindset in Navigation Ability (partial correlation with SBOSD, $r = -.05$, $p = .61$; partial correlation with SA, $r = -.04$, $p = .63$). In contrast, after controlling for General Growth Mindset, GMN is significantly correlated with SBSOD (partial correlation $r = .39$, $p < .001$) and Spatial Anxiety (partial correlation $r = -.39$, $p < .001$). This analysis indicates that general growth mindset is partially dissociated from growth mindset in navigation ability. It suggests that, as predicted, people with growth mindset in navigation ability have more confidence in their navigation ability, less anxiety during navigation, and are more likely to explore environments.

Exploration Tendency (ET), with Cronbach's Alpha of .80, is a promising measure, which is moderately correlated with SBSOD, Spatial Anxiety, GPS Dependency and the Map Perspective Taking test. That is, people who are more likely to explore environments tend to minimize use of GPS, $r = -.33$, $p < .001$, and have better perspective taking ability (LMPT $r = -.20$, $p = .02$ and LOPT $r = -.17$, $p = .07$)[4].

GPS Dependency also shows links to SBSOD, Spatial Anxiety and Object Perspective Taking, suggesting that people who rely less on GPS tend to have better performance in orientation tasks. However, the reliability (Cronbach's Alpha = .70) of this scale is limited.

Finally, people with a better sense of direction (a high SBSOD score), are more likely to have a growth mindset with respect to navigation ($r = .45$, $p < .001$) are less likely to experience anxiety during navigation, $r = -.63$, $p < .001$, more likely to explore environments, $r = .48$, $p < .001$, and are less likely to rely on GPS, $r = -.41$, $p < .001$. The results also indicate that SBSOD has significant correlations with objective spatial ability measures, replicating previous research (Hegarty et al., 2018). Specifically, people who report a good sense of direction have less angular error on the OPT, $r = -.18$, $p = .05$[5], and MPT, $r = -.22$, $p = .01$.

2.3. Discussion

Study 1 contributed new measures of growth mindset in navigation ability, exploration tendency, and GPS dependence during navigation and revealed relations between these measures and existing measures. Specifically, it showed that people's growth mindset in navigation ability is partially dissociated from their general growth mindset, and that people are less likely to have a growth mindset with respect to navigation ability than with respect to intelligence. It also provided preliminary evidence for some of the relationships proposed in our conceptual model. Specifically, results indicate that people holding growth mindsets in regard to navigation ability tend to explore their environments more. Moreover, spatial anxiety is negatively related to exploration and positively related to use of GPS technologies while these navigation behaviors are related to self-report sense of direction (SBSOD).

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 was fixed, and carry-over effects may cause Growth Mindset scales to set up an initial general mindset about navigation for participants so that the overall correlations between scales are inflated. Also, even if the Pearson correlation (r) between SBSOD, Spatial Anxiety and other properties is high, other analyses are needed to examine whether these variables explain the same variance before making conclusions. In Study 2 regression and mediation models were built and examined to further understand these relationships after scale revision.

3. Study 2

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 feedback from participants in Study 1. The updated scales are available on the Open Science Framework website at https://osf.io/6ezpw/. In addition, the order of the questionnaires was randomized to control for carry-over effects. Based on these improved scales and procedures, regression and mediator models were built to examine the associations and dissociations between measures.

One limitation of the GPS Dependency Scale used in Study 1 is that the items share similar scenarios with the Spatial Anxiety Scale, which may have inflated the associations between GPS Dependency and Spatial Anxiety. Also, all items 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 completely new to them. In Study 2 the scales were revised to address these issues.

3.1. Method

3.1.1. Participants

One hundred fifty undergraduate students (78 females and 72 males) participated in this study for course credit. A sample size of 150 was larger than Kline's (2015) recommended minimum 10:1 parameter: sample size ratio for adequate power. In addition, the sample size was sufficiently powered (greater than 0.8 which occurs at a sample size of 148 when using bias-corrected bootstrapping) to detect a modest (mean $\tau' = .067$) indirect effect (Fritz & MacKinnon, 2007).

3.1.2. Materials

As in Study 1, all scales were administered via the Qualtrics platform. Study 2 used the same scales for measuring general growth mindset (GGM) and navigation ability (SBSOD: Santa Barbara Sense of Direction).

Measure of Growth Mindset in Navigation Ability. Although students were given a definition of navigation ability in Study 1, feedback from participants regarding the Growth Mindset in Navigation Ability (GMN) scale, suggested that the phrase "navigation ability" was not familiar to some participants and they asked whether "navigation ability" means the same thing as "sense of direction". Given that "sense of direction" is the term used in everyday conversation, the words "navigation ability" were replaced by the words "sense of direction" in the updated scale and we deleted the description of "navigation ability."

Measure of GPS Dependency. To revise the GPS Dependency Scale, four prior items were reworded to make the items distinct from the items in Spatial Anxiety Scale, and four additional items related to navigation in relatively familiar environments were added, for example, "I feel anxiety when returning from a familiar place to my home, if I have never gone home directly from this place before".

Measure of Spatial Anxiety. 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 focused on spatial anxiety during navigation instead of including spatial anxiety in other scenarios, such as mental rotation.

Measure of Exploration Tendency. For the Exploration Tendency Scale, four items were added, which were items with more specific scenarios (e.g., trying a new route during traffic congestion) and items related to exploration tendency included in a previously developed scale (Pingel, 2010).

Measure of Perspective Taking. 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 min, this time limit was used in Study 2.

3.1.3. Procedure

Participants were tested in groups of up to six students per session but worked independently. They first completed the OPT. After they completed this test or reached the 5-min time limit, they completed the six questionnaires, which were administered in a random order.

3.2. Results

3.2.1. 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 and scores were log transformed to remedy this departure, creating a new variable LOPT.[6] The reliability for the scales measuring exploration tendency (ET), GPS dependency (GPS) and spatial anxiety (SA) were 0.86, 0.81, and 0.90 respectively, suggesting that the scales improved after revision.

Consistent with Study 1, participants reported more general growth mindset than growth mindset in sense of direction, paired-samples $t(147) = 5.56$, $p < .001$, $d = 0.50$, 95% CI is [0.30, 0.61]. This difference was larger than that in Study 1 ($d = 0.31$). While the mean General Growth Mindset rating was the same in both studies (3.6), the mean for Growth Mindset in Sense of Direction in this study (3.1) was significantly lower than the mean for Growth Mindset in Navigation Ability in Study 1 (3.4), $t(271) = 2.46$, $p = .014$, $d = 0.23$, 95% CI is [0.05, 0.42]. These results again indicate that people are more likely to believe that their sense of direction is fixed (not malleable) than that their intelligence is fixed.

Table 4 presents the Pearson correlations between variables. General Growth Mindset was correlated with Growth Mindset in Sense of Direction. However, this correlation, $r = .42$, $p < .001$, is significantly lower than that in Study 1($r = 0.60$), $z = 1.99$, $p = .05$. Moreover, the significant correlations of Growth Mindset in Navigation Ability with Spatial Anxiety and Exploration Tendency in Study 1 were not replicated. These results suggest that the everyday term "sense of direction" is not synonymous with navigation ability at least as it was defined in Study 1. Although Study 2 randomized the order of all questionnaires, the significant correlations between SBSOD and all of the other scales were replicated. Specifically, people with a good sense of direction are more likely to believe that their navigation ability can be improved, feel less anxiety during navigation, are more willing to explore new places, tend to rely less on GPS, and show better perspective taking performance (see Table 4).

With the improved reliability of the Exploration Tendency and GPS Dependency scales, these scales now have stronger relations with Spatial Anxiety (SA), and sense of direction, as indicated by the correlations in Table 4. Perspective taking ability, measured by the error score on the LOPT, is significantly correlated with SBSOD, Spatial Anxiety, and marginally correlated with GPS Dependency, as shown in Table 4[7].

3.2.2. Model 1: simultaneous multiple regression model

Correlations only reveal relations that do not control for effects of other variables. Thus, a simultaneous regression analysis was conducted to detect what proportion of the variation in self-reported sense of direction (SBSOD) can be uniquely explained by different variables. Since SBSOD is a good predictor of objective navigation ability (Hegarty et al., 2002; 2018), the SBSOD is treated as the dependent variable in the regression model to infer how other variables are related to navigation ability. Four predictor variables were examined: Growth Mindset in Sense of Direction (GMSOD), Spatial Anxiety (SA), Exploration Tendency (ET) and GPS Dependency (GPS). Together these variables

[6] Thirteen participants (6 females and 7 males) did not complete the OPT within the 5-min time limit. However, 94% of them completed more than 10 trials. Therefore, no strong evidence supports omitting these participants' performance, Participants' score on the OPT is calculated based on the completed trials and the results did not differ appreciably if these participants were not included in the analysis so analyses based on all participants' performance are presented here. One male participant failed to do the OPT experiment and One female participant failed to report her SA data due to technical issues. These two cells were treated as missing values and were discarded in the following analysis.

[7] Gender differences were not the focus of this study, but men are more likely to report high SBSOD, to report less anxiety, to explore new routes and to report lower dependence on GPS. Also, replicating previous studies in perspective-taking tests, men outperformed women in OPT. However, no gender difference emerged from General Growth Mindset Scale nor Growth Mindset in Sense of Direction Scale.

Table 2
Univariate correlations between study measures for study 1.

	1	2	3	4	5	6	7
1. GGM	—						
2. GMN	.60***	—					
3. SBSOD	.24**	.45***	—				
4. SA	-.24**	-.45***	-.63**	—			
5. ET	.16	.30***	.48***	-.50***	—		
6. GPS	-.03	-.14	-.41***	-.50***	-.33***	—	
7. LOPT	.00	-.11	-.18	.23*	-.17	.20*	—
8. LMPT	.08	-.01	-.22*	.15	-.20*	.11	.73***

Note. N = 123. The values of the correlations plus the significance levels as stars. * indicates $p < .05$. ** indicates $p < .01$. *** indicates $p < .001$.

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
GMSOD	1.0	5.0	3.1	0.8	−0.1	−0.6	0.94
SBSOD	1.5	6.2	4.0	1.1	−0.1	−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; GMSOD: Growth Mindset in Sense of Direction; 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.

explained 45% of the variance in SBSOD, $R^2 = 0.45$; $F(4, 143) = 28.63$, $p < .001$. 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 strongest predictors. A collinearity check, conducted using the indicator of variance influence factor (VIF), demonstrated that there is no severe issue of collinearity (Cohen, Cohen, West, & Aiken, 2013). All predictors explained unique variance in the dependent variable (SBSOD), here used as a proxy for a person's navigation ability (see Table 5).

3.2.3. Model 2: partial mediator model

Model 2.1.1. It was hypothesized that high spatial anxiety would be negatively correlated with sense of direction (SBSOD) as in previous research (e.g., Lawton, 1994; Lawton & Kallai, 2002). A novel prediction of the present work was that this effect would be mediated by Exploration Tendency (ET) and GPS Dependency (GPS). That is, we predicted that people with high spatial anxiety would report poor navigation ability because they are less likely to explore their environments and are more likely to rely on GPS, and therefore would have less navigation experience. Results are summarized in Fig. 4.

First, as expected, high spatial anxiety was associated with a poor sense of direction (SBSOD), $b = -0.67$, $\beta_c = -0.48$, $p < .001$. Second, as predicted, people with high spatial anxiety were less willing to explore new places, $b = -0.39$, $\beta_{a1} = -0.57$, $p < .001$, and more likely to rely on GPS, $b = -0.46$, $\beta_{a2} = 0.44$, $p < .001$. Third, when SBSOD was regressed on SA, ET, and GPS simultaneously, the paths linking all three variables to SBSOD were significant; $b = 0.32$, $\beta_{b1} = 0.33$, $p < .001$ for Exploration Tendency; $b = -0.45$, $\beta_{b2} = -0.30$, $p < .001$ for GPS Dependency. 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: $b = -0.21$, $\beta_{c'} = -0.16$, $p < .001$).

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 = −0.1854, SEIE1 = 0.0502, 95%CI = [-0.2847, −0.0893]; IE2 = −0.1338, SEIE2 = 0.0379, 95%CI = [-0.2097, −0.0604]), indicating that, as predicted, Exploration Tendency and GPS Dependency partially mediated the relationship between Spatial Anxiety and SBSOD (Revelle, 2018).

Taken together, these findings indicate that people with low spatial anxiety are more likely to have a good sense of direction, and this is mediated (at least in part) by their greater tendency to explore environments and less dependency on GPS. These findings support the Spatial Anxiety Model proposed in section 1.7 (see Fig. 1).

Model 2.1.2. The Growth Mindset Model proposed in section 1.7 (see Fig. 1) was also tested. The results of this mediation model are summarized in Fig. 5. However, the model was not supported due to the weak links between GMSOD and Exploration Tendency and GPS Dependency.

Model 2.2: An alternative model was also built to test a causal model in which spatial anxiety is seen as mediating the relationship between navigation ability (as measured by the SBSOD) and navigation behaviors. Specifically, this model proposes that relative to people with high SBSOD, those with low SBSOD have more spatial anxiety and this anxiety causes them to avoid exploring their environments and rely more on GPS. The results of this alternative model are summarized in Fig. 6.

First, people with good navigation ability were more likely than people with poor navigation ability to report low dependence on GPS ($b = -0.369$, $\beta_{c1} = -0.53$, $p < .001$) and high exploration tendency ($b = 0.583$, $\beta_{c2} = 0.56$, $p < .001$). Second, people with good navigation ability were less likely to show spatial anxiety ($b = -0.339$, $\beta_a = -0.48$, $p < .001$). 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 depend on GPS ($b = 0.242$, $\beta_{b1} = 0.25$, $p = .002$) and less likely to explore their environment ($b = -0.566$, $\beta_{b2} = -0.39$, $p < .001$). Importantly, the original associations between SBSOD and Exploration Tendency as well as GPS Dependency were reduced when including Spatial Anxiety as a mediator but remained significant (direct effect: $b_1 = -0.287$, $\beta_{c1'} = -0.41$, $p < .001$; $b_2 = 0.392$, $\beta_{c2''} = 0.37$, $p < .001$).

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). Results based on 5000 bootstrapped samples revealed that the indirect effect was statistically significant (IE1 = −0.1180, SEIE1 = 0.0453, 95%CI = [−0.2158, −0.0428]; IE1 = −0.1853, SEIE1 = 0.0509, 95%CI = [-0.2158, −0.0428]), indicating that Spatial Anxiety partially mediated the relationship between SBSOD and Exploration Tendency as well as GPS Dependency.

Model 2.1.1 and Model 2.2 were compared using the 10-fold Cross Validation procedure (Maindonald & Braun, 2019; see also, Kohavi, 1995). Specifically, the sample was divided into ten groups randomly. Nine training groups were used to develop the tested model and the other group was used to predict GPS Dependency and Exploration Tendency based on the values of all independent variables. The mean square error was calculated based on the predicted values and the actual values of GPS Dependency and Exploration Tendency reported by participants. This procedure was repeated ten times by treating each group as a testing group once and the average values of mean square errors were used to indicate prediction accuracy of the models (a higher mean square error indicates a lower accuracy in prediction). The prediction accuracy of Model 2.1.1 (0.622) shown in Fig. 4 (Spatial Anxiety leads to low SBSOD) slightly outperforms this alternative Model 2.2 shown in Fig. 6 (0.641). However, both models showed good fit, suggesting that this alternative model cannot be ruled out based on the data collected in this study.

Table 4
Univariate correlations between study measures for study 2.

	1	2	3	4	5	6
1. GGM	—					
2. GMSOD	.42***	—				
3. SBSOD	.16*	.24**	—			
4. SA	-.02	-.07	-.48***	—		
5. ET	.06	.14	.56***	-.57***	—	
6. GPS	-.02	-.13	-.53***	.44***	-.47***	—
7. LOPT	.09	-.11	-.32***	.18*	.10	.14

Note. N = 149. The values of the correlations plus the significance levels as stars. * indicates $p < .05$. ** indicates $p < .01$. *** indicates $p < .001$.

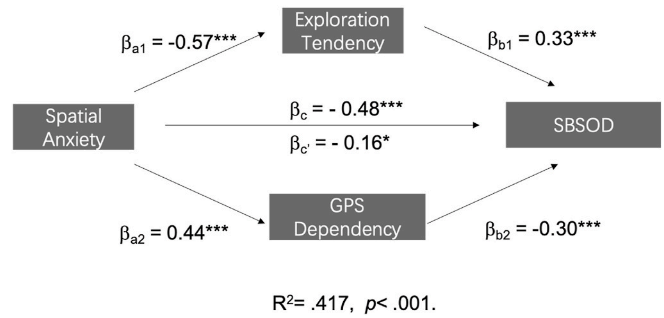

Fig. 4. Summary of the Hypothesized Mediator Model 2.1.1 in Study 2. N = 149. Path coefficients shown here are standardized regression coefficients(β). Unstandardized coefficients (b) are reported in the text. *p < .05. ***p < .001. β_c indicates the standardized correlation between SA and SBSOD, $\beta_{c'}$ indicates the standardized direct effect of SA on SBSOD controlling for two indirect effects.

3.3. Discussion

The reliability of the new Exploration Tendency and GPS Dependency scales was improved following revision of these scales in Study 2 and the revised Spatial Anxiety Scale, which focuses mainly on spatial anxiety during navigation, was also reliable. Model 2.1.1 supports the general model proposed in Fig. 1, indicating that exploration tendency and GPS dependency mediate the relationship between anxiety and navigation ability. Specifically, it suggests that people with high spatial anxiety may have poor navigation ability, in part because they are less willing to explore their environment and are more dependent on GPS.

It is noted that mediation Model 2.2 is also supported by the data, suggesting that we cannot rule out the alternative causal direction that spatial anxiety mediates the relationship between self-reported sense of direction and navigation behaviors, namely exploration and GPS use. Both models reveal that navigation ability, spatial anxiety and behaviors (exploration and GPS use) are related. They differ in whether differences in spatial anxiety lead to different self-reported sense of direction or whether differences in self-reported sense of direction lead to different spatial anxiety. It is noted that Model 2.1.1 and Model 2.2 are both essentially correlational models so they cannot establish direction of causality. Thus, the results of our study, due to close relationship between these variables and lack of direct experimental manipulations, can be used to support either direction of causality. From the perspective of conceptual theories, it is possible that both directions of causality are operating, that is, people do not explore because they have high spatial anxiety or a poor sense of direction, but this then becomes a self-

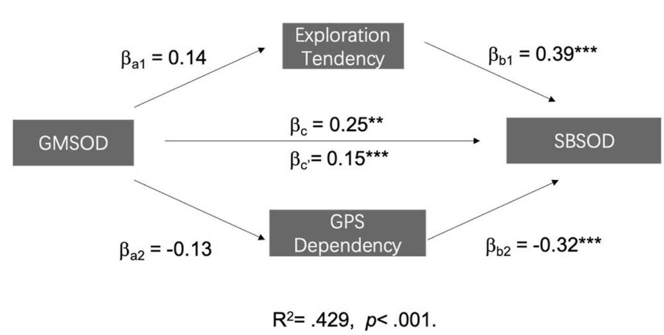

Fig. 5. Summary of the Hypothesized Mediator Model 2.1.2. N = 150. Path coefficients shown here are standardized regression coefficients(β). Unstandardized coefficients (b) are reported in the text. *$p < .05$. ***$p < .001$.β_c indicates the standardized correlation between GMSOD and SBSOD, $\beta_{c1'}$ indicates the standardized direct effect of GMSOD on SBSOD controlling for two indirect effects.

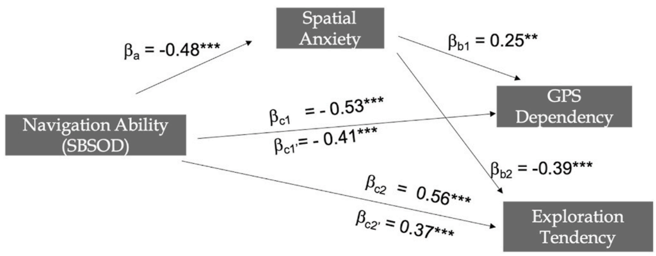

Fig. 6. Summary of the alternative mediator Model 2.2. N = 150. Path coefficients shown here are standardized regression coefficients(β). Unstandardized coefficients (b) are reported in the text. *p < .05. ***p < .001.β_{c1} indicates the standardized correlation between SBSOD and GPS Dependency, $\beta_{c1'}$ indicates the standardized direct effect of SBSOD on GPS Dependency controlling for the indirect effect. β_{c2} indicates the standardized correlation between SBSOD and Exploration Tendency, $\beta_{c2'}$ indicates the standardized direct effect of SBSOD on Exploration Tendency controlling for the indirect effect.

fulfilling prophecy such that they get less experience at navigation and consequently do not develop their navigation abilities. In the future, longitudinal studies, including training programs, can be developed to establish the direction of causality.

Although General Growth Mindset and Growth Mindset in Sense of Direction (GMSOD) were correlated, GMSOD did not show strong associations with navigation behaviors in Study 2, in contrast to Growth Mindset in Navigation Ability (see in Study 1). There are three possible reasons for this result. First, "navigation ability" was defined in Experiment 1, whereas "sense of direction" was not defined in Study 2. This construct might also need an explanation, because some people may interpret "sense of direction" more metaphorically (e.g., I have a good sense of my direction in life). Note that the average score of the scale used in Study 1 ("navigation ability") is significantly higher than that of the scale used in Study 2 ("sense of direction"), which may suggest these two terms are conceptually different to participants. Second, reference to "ability" in the term "navigation ability" may have suggested a closer relation with an ability or skill. In contrast, "sense of direction" may be closer to a personality trait than an ability (Condon et al., 2015), which is more likely to be considered to be fixed. Third, in Study 1, the GMN was administered first, whereas Study 2 used a randomized order of questionnaires. It is possible that Growth Mindset in Navigation Ability influenced participants' dispositions and responses to the following navigational measures in Study 1.

Although growth mindset was not a strong predictor of SBSOD, the coefficient for the variable (GMN) did not change much after controlling for other factors in a simultaneous regression. That is, it explained unique variance in navigation ability. This result highlights that this understudied motivational disposition may still play an essential role in navigation ability development. The main function of growth mindset, according to the literature, is leading to adaptive actions in daily life such as encouraging people to train themselves and approach challenges. However, the weak links between GMN and two navigation behavior scales (ET and GPS Dependency) call for future examination.

Table 5
Simultaneous regression analysis predicting self-report navigation ability.

Predictor Variable	*b*	95% CI for *b*	*β*	sr^2	*r*	VIF
Growth Mindset (in sense of direction)	.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 = conf idence interval; β = standardized partial regression coefficient; = squared semi-partial correlation (total variance uniquely explained by the variable). = 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.

4. General discussion

In two studies, we developed new reliable measures of three constructs that have not previously been systematically studied in the spatial cognition literature, namely, Exploration Tendency, GPS Dependency, and Growth Mindset in Navigation Ability (Sense of Direction). In addition, the Spatial Anxiety scale (Lawton, 1994; Lawton & Kallai, 2002; Lyons et al., 2018) 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 during navigation tend to report more exploration of environments and less dependence on GPS. These participants also report a good sense of direction (high SBSOD score) and show less angular error in perspective taking tasks, which are objective measures related to navigation ability.

This paper introduced the concept of growth mindset in navigation ability (sense of direction). An interesting result, replicated in both studies, is that people have a more fixed mindset with respect to navigation ability than with respect to general intelligence. That is, they are less likely to believe that their navigation ability (or sense of direction) can be improved than they are to believe that their intelligence can be improved. This poses a challenge for efforts to train people to be better navigators.

The results of mediation analyses supported a novel model of how emotional disposition might affect navigation ability. This model proposes that the link between spatial anxiety and navigation ability is mediated by navigation behaviors. Specifically, two measures of navigation behavior, exploration and GPS use, were found to mediate the relationship between spatial anxiety and navigation ability. Our results suggest that people who have high spatial anxiety are less likely to explore their environments and rely more on GPS. We propose that people's spatial anxiety influences these navigation behaviors such that they get less practice at navigation and therefore do not have a chance to develop their navigation ability.

However, the proposed mediation model of how mindsets might affect navigation ability was not supported due to weak links between growth mindset in sense of direction and navigation behaviors, namely exploration and GPS use. Instead, a multiple regression analysis presented in Study 2 suggests that growth mindset explains unique variance in navigation ability independently of navigation behaviors. This result suggests that growth mindset is related to navigation ability but this relation is not mediated by exploration or GPS use. One possible reason why we did not observe the proposed mediation is that ours was not a longitudinal study. Growth mindset might have larger effects in a training study, where people with growth mindsets would be expected to show greater improvements in navigation after training than those with fixed mindsets.

Another possible reason relates to how growth mindset was measured. A limitation of our research is that we measured this construct differently in the two studies, and found somewhat different results, suggesting that more research is needed on the development of measures of this construct. In Study 1, we measured growth mindset with respect to "navigation ability" which was defined. In Study 2 we measured growth mindset with respect to "sense of direction" which was not defined. When researchers use self-report surveys, they typically do not explicitly define terms such as navigation ability or sense of direction. Our results highlight that the definition of these constructs might not be intuitive to participants, a point which should be considered in future research.

Another limitation of the current work is that we used only indirect measures of navigation ability (i.e., perspective taking) and self-report surveys of dispositions (sense of direction and spatial anxiety) and navigation behaviors. More objective measures of navigation, such as ability to learn the layout of novel real-world environments (e.g., Ishikawa & Montello, 2006; Schinazi, Nardi, Newcombe, Shipley, & Epstein, 2013) or wayfinding in learned virtual environments (e.g., Boone, Gong, & Hegarty, 2018; Marchette, Bakker, & Shelton, 2011) should be used in future studies. We expect that our results will generalize to more objective measures, because other studies have found that objective measures of navigation ability, such as pointing to cardinal directions, route-tracing and shortcutting tasks correlate with emotional, motivational and personality traits (Meneghetti et al., 2014; 2020; Pazzaglia et al., 2017; 2018), although these studies measured somewhat different traits (e.g. self-efficacy and pleasure in exploring new places). On the other hand, the promising self-report results from our study suggest that participants are conscious of their spatial abilities and anxieties and so these properties can be measured by self-report in future, although more objective measures of exploration and GPS use should be also considered.

The malleability of navigation ability, which is a strong assumption under mindset theory, has not been investigated comprehensively to date (but see Lovden et al., 2012; Woollett et al., 2009; McLaren--Gradinaru et al., 2020 for preliminary studies). The main way to study the malleability of navigation ability would be to conduct a training program to investigate if a growth mindset predicts whether and how much people improve their navigation ability after training. However, in order to design a training program, researchers need to better understand what experiences or teachable strategies are associated with good navigators. A main practical implication of the present studies is that setting a growth mindset and relieving participants' anxiety during navigation should be preliminary steps in the training program.

There are increasing concerns that we may be losing our navigation competencies by not exercising these competencies and relying too much on GPS technologies (Dahmani & Bohbot, 2020; Gardony et al., 2015; Ishikawa et al., 2008). We do not mean to suggest that people should never use GPS technologies or spend unnecessary effort exploring environments that they may visit only once. However, we suggest that overreliance on GPS technologies may prevent people from exercising their natural navigation abilities so that they do not develop these abilities. This could have serious consequences when cellphone signals are unavailable, for example, due to battery loss. A novel finding of our study is that overreliance on GPS may be related to spatial anxiety. We suggest that if people are willing to explore new environments and avoid GPS use when they have time, they may develop better navigation skills and this in turn may alleviate spatial anxiety.

Overall, this research study is the first to link growth mindset to navigation ability and develop reliable questionnaires to measure growth mindset in navigation ability, GPS dependency and exploration tendency. It is the first to link motivational and emotional dispositions to navigation ability by considering navigation behaviors as mediators. The results highlight how beliefs and consequent navigation efforts may influence individual differences in navigation tasks over and above basic ability. Studying the malleability of navigation ability in the future calls for understanding adaptive navigation dispositions, and how they lead to effective environmental learning strategies. This study paves a new path for understanding navigation development and inspires future training programs in navigation.

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Author contribution

Chuanxiuyue He: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing-Original Draft, Writing- Review & Editing, Visualization, Project administration. **Mary Hegarty**: Conceptualization, Methodology, Validation, Writing- Review, Supervision.

Declaration of competing interest

None.

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