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Video gaming, but not reliance on GPS, is associated with spatial navigation performance

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ABSTRACT

Recent evidence suggests that greater reliance on GPS-assisted devices is associated with poorer navigation ability. Studies have also shown that video gaming may be associated with navigation ability. We investigated the effect of video game experience and reliance on GPS on navigation ability using the mobile app Sea Hero Quest, which has been shown to predict real-world wayfinding performance. We tested a group of US-based participants' wayfinding performance (n = 822, 367 men, 455 women, mean age = 26.3 years, range = 18–52 years) and asked them a series of questions relating to reliance on GPS and video game experience. A multiple linear regression model found no significant association between reliance on GPS and wayfinding performance. There was a significant association between weekly hours of video gaming and wayfinding performance. These findings provide a platform for future intervention-based research studies investigating whether daily activities may causally enhance or disrupt specific cognitive abilities.

1. Introduction

Being able to maintain a sense of direction and location in order to find our way in different environments is a fundamental cognitive function that relies on multiple cognitive and perceptual processes (Newcombe et al., 2022; Spiers et al., 2023; Wolbers & Hegarty, 2010). Human navigation involves a range of processes such as planning routes, reading maps, identifying landmarks and maintaining a sense of direction (Ekstrom et al., 2018; Newcombe et al., 2022). Getting lost in everyday environments can lead to distress for patients and family members and in extreme cases death from exposure (Coughlan et al., 2018). Additionally, navigation deficits may constitute the earliest signs of Alzheimer's Disease (Coughlan et al., 2018) and be apparent in other disorders such as Traumatic Brain Injury (Seton et al., 2023). Despite the importance of being able to navigate in everyday life, a spectrum of individual differences in navigation abilities has been observed in previous studies (Newcombe et al., 2022). By understanding individual differences in navigation abilities, we can further understand how different factors may contribute to this important cognitive function. The goal of this research is to examine how two modern day technologies, video games and GPS-assisted navigation devices, are related to navigation abilities.

Understanding how daily activities influence individual differences in navigation ability is important given that the use of rising modern-day technologies may both exercise one's navigation abilities, e.g. potentially video games, and be used to offload the cognitive processes that normally occur during navigation, e.g. GPS-assisted devices. However, the impact of video games and reliance on GPS has not been directly tested at a large scale using an objective navigation task. Creating a valid test of navigation that accounts for the wide variation in navigation ability is challenging, given the large sample sizes needed, high levels of environmental manipulation and experimental control required in standard research settings and the multifaceted nature of navigation ability (Newcombe et al., 2022). However, with the recent evolution of widespread touch-screen technology, our team developed a mobile video game app Sea Hero Quest (SHQ) (Spiers et al., 2023). SHQ has

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since been used to test the wayfinding ability of 4 million people globally, has good test-retest reliability and is predictive of real-world wayfinding performance (Coughlan et al., 2020; Coutrot et al., 2018, 2019), making it a valid tool for testing wayfinding performance. Associations between lifestyle factors, such as the environment one grew up in, and wayfinding performance have also shown to be similar in strength regardless of whether wayfinding ability was tested using SHQ or a city-like environment (Coutrot, Manley, et al., 2022). As with SHQ (Coutrot et al., 2019), other studies have also indicated that virtual environments provide a reliable means of assessing navigation in a manner that is strongly linked to real-world performance (Clemenson et al., 2020; Hejtmanek et al., 2020; Richardson et al., 1999).

A key daily activity that is increasing in prevalence and may exercise different cognitive processes related to wayfinding performance is video gaming (Engelstätter & Ward, 2022; McLaren-Gradinaru et al., 2023). Studies have shown that those who report playing video games used more efficient navigation strategies for orientation such as using cognitive maps or learned routes (Murias et al., 2016). Additionally, playing video games was found to be detrimental or beneficial to one's spatial memory performance depending on whether a player used a counting strategy or used visual landmarks to find a goal's location (West et al., 2017). Thus, one possible theory is that different facets of spatial cognition may be exercised through video game experience, resulting in better navigation ability, however, to date, this has not been evaluated with a large sample.

Another daily activity aside from video game playing that is also increasing in prevalence and has been associated with navigation ability is GPS use (He & Hegarty, 2020; McKinlay, 2016; Topete et al., 2024). Instead of exercising cognitive abilities, relying on GPS is offloading cognitive processes to the devices. Numerous studies have suggested that using GPS-based systems may be detrimental to human navigation performance, as assessed using self-report questionnaires, computerised and real-world tests (Dahmani & Bohbot, 2020; Fenech et al., 2010; Gardony, Brunyé, & Taylor, 2015; He & Hegarty, 2020; Hejtmanek et al., 2018; Ishikawa et al., 2008; Ishikawa, 2018; Kippel et al., 2010; Parush et al., 2007; Ruginski et al., 2019; Schwering et al., 2017; Willis, Hölscher, Wilbertz, & Li, 2009). For example, the negative effect of spatial anxiety on one's self-reported sense of direction was mediated by a greater self-reported reliance on GPS (He & Hegarty, 2020), and greater reliance on GPS was significantly associated with poorer spatial memory when participants were required to find the location of target paths in an environment they had learnt without using GPS (Dahmani & Bohbot, 2020). It has also been proposed that people rely on GPS and therefore do not exercise and develop their navigation (He & Hegarty, 2020). However, it remains unclear and untested how self-reported reliance on GPS is associated with wayfinding ability in a large sample.

Bringing together these findings, we aimed to investigate whether reliance on GPS and video gaming experience would be independently associated with wayfinding ability in a large sample. Based on the research reviewed above, we firstly hypothesised that those with more hours of video gaming experience per week would show better wayfinding performance. Secondly, we hypothesised that those with a greater reliance on GPS would show worse wayfinding performance. Based on past evidence (McLaren-Gradinaru et al., 2023), we also explored whether any gender differences in wayfinding performance would be mitigated when video game experience is accounted for, whether there was an interaction between gender and reliance on GPS on wayfinding performance (Miola et al., 2023), and whether there was an association between video game genre and wayfinding performance (Leonhardt & Overå, 2021).

2. Methods

2.1. Participants

903 participants living in the US aged 18 and above (309 men, 575 women, other, mean age = 27.0 years, SD = 8.0 years, range = 18–66 years, mean number of years of formal education = 16.1 years)[1] were recruited using the Prolific database (www.prolific.co, 2023) and reimbursed for their time. Ethical approval was obtained from the University College London Review Board conforming to the Declaration of Helsinki (World Medical Association, 2013). All participants provided informed written consent. We removed 19 participants who selected 'other' for gender as we believed it would be hard to make any informative interpretation of any findings with this limited sample size. We then further identified multivariate outliers in this remaining sample of participants using Mahalanobis' Distance (see Supplementary Materials). Mahalanobis Distance has been shown to have high sensitivity and specificity and a minimal change in bias in simulated and real datasets when removing multivariate outliers based on questionnaire data compared to other methods (Curran, 2016; Ward & Meade, 2022; Zijlstra et al., 2011). 67 participants were removed as outliers.[2] This resulted in a final sample size of 817 participants (361 men, 456 women, mean age = 26.3 years, SD = 6.7 years, range = 18–52 years, mean number of years of formal education = 16.1 years). Demographic information for the final sample is summarised in Table 1. Data analysis was completed using R (R studio version 1.4.1564, R version 4.1.2) and Python (version 3.9.12).

2.2. Statistical power analysis

An a priori power analysis was conducted using G* power (Erdfelder et al., 1996), using a linear multiple regression model with 6 predictor variables (see 'Data Analysis' section of Methods). With a total sample size of 822 participants, a small effect size (Cohen's f2 = 0.03) at an alpha threshold of 0.05 was sufficient to warrant a 98% chance of correctly rejecting the null hypothesis (0.98 power) (Selya et al., 2012).

2.3. Experimental procedure

2.3.1. Self-report questionnaires

To characterise one's reliance on GPS, the GPS reliance scale was used (Dahmani & Bohbot, 2020). This scale has seven items and assesses the frequency at which people have relied on GPS in different situations

Table 1
Summary of basic descriptive statistics for the variables included in the model.

	Women	Men
n (%)	456 (55.8%)	361 (44.2%)
Weighted wayfinding distance (VR-m)	12.2 (3.3)	10.7 (3.5)
Age in yrs	24.9 (5.9)	28.1 (7.3)
Average GPS reliance score (1–5, Max. 5)	3.7 (0.7)	3.4 (0.8)
Weekly hours of phone use	36.3 (23.2)	28.4 (21.5)
Weekly hours of video game use on all devices	4.7 (5.3)	10.2 (6.3)

These were: weighted wayfinding distance, age, weekly hours of video game use on all devices, weekly hours of phone use, for men and women separately, and across gender. Mean and standard deviation (SD) values are shown. For weighted wayfinding distance, the raw (not z-scored) wayfinding distance is shown. VR-m = virtual reality metres.

[1] The majority of our participants were under 35 years of age. Only 1 participant was above 50 years of age.

[2] We do not consider this to be too large a number of outliers to remove given that this study was conducted online using Prolific, and thus the sample used here were sampled opportunistically. We also applied relatively strict criteria to the Mahalanobis' distance calculation which we used to identify the outliers. When we used a more conservative threshold (alpha = 0.01) to identify outliers using Mahalanobis' distance, removing 37 outliers, our model outputs remained unchanged (see Supplementary Materials Table S15).

within the past month (e.g., "How often do you use GPS to travel new routes to a previously visited destination?"). The average score across questions was calculated for each participant.

To characterise video game use, participants were asked to indicate the number of hours per week spent playing video games on all devices per week, as well as specifically on a phone or tablet, the number of hours of phone use per week, their most commonly played video game genre and the video game platform they used most often.

Participants were also asked to report their age, gender, highest education level and to complete the navigation strategies questionnaire (indicating their tendency to use a map-based navigation strategy in everyday life). Please see Supplementary Materials for the full set of questionnaires.

2.3.2. Sea Hero Quest task

Sea Hero Quest (SHQ) is a VR-based video game for mobile and tablet devices which requires participants to navigate through a three-dimensional rendered world in a boat to search for sea creatures in order to photograph them, with the environment consisting of ocean, rivers and lakes (Coutrot et al., 2018; Spiers et al., 2023) (Fig. 1). We asked participants to play 5 levels - levels 1, 11, 32, 42 and 68 - where level 1 was a tutorial level designed to assess one's ability to control the boat, whilst the latter 4 levels were wayfinding levels. We selected these specific levels as they showed the greatest effect sizes when investigating the effect of one's home environment on wayfinding performance in a previous study (Coutrot, Manley, et al., 2022). The wayfinding levels increased in difficulty from level 11 to 68, with the difficulty of a given level based on the number of goals and how far apart they were from each other (see Yesiltepe et al., 2023). Participants were required to play all 5 levels, where playing a given level would unlock the next level. For each participant, we quantified the wayfinding distance, defined as the euclidean distance travelled between each sampled location in pixels, for levels 11, 32, 42 and 68 separately. We then divided the wayfinding distance in each level by the wayfinding distance in level 1 to control for the effects of game experience on navigation performance. To control for the difference in wayfinding distance between levels, we then z-scored the distances within each level and averaged these across the levels. This resulted in each participant having a z-score which represented their wayfinding distance across the 4 levels. This z-score was referred to as the weighted wayfinding distance. A shorter weighted wayfinding distance indicated better navigation performance (i.e., a more efficient route to the goal).

2.3.3. Data Analysis

Firstly, we examined the validity and reliability of all multi-item self-reports (see Supplementary Materials). We removed the fifth question of the GPS reliance scale - "You usually travel a specific route to go to your friend's house. This time, you think you may get there faster by taking a different route. How often do you take new routes to travel to places you have visited before?" - as we did not believe this was assessing reliance on GPS. (Removing this item had minimal effect on the internal reliability of the scale - see Supplementary Materials). The Navigation Strategy Questionnaire is not included in the main text due to its inadequate psychometric characteristics (see Supplementary Materials). However, we did explore how navigation strategy use may influence the effects of video gaming and GPS reliance on navigation ability by accounting for navigation strategy scores in a supplementary model (Supplementary Table S7). This was motivated by the fact that during the SHQ Wayfinding task, participants study the map from an allocentric ("survey") perspective but then perform the navigation from a surface-level third-person egocentric ("route") perspective.

We then conducted a multiple linear regression model to analyse the effects of average GPS reliance score and hours of video game use per week on all devices on wayfinding distance. To explore how the effect of gender on navigation performance was influenced by GPS reliance and video game experience, we included a GPS reliance x gender and an hours per week video game use × gender interaction terms in the model. Age, gender and highest level of education were included in the model as covariates given their previous association with wayfinding distance (Coutrot et al., 2018; 2022a). Given that familiarity of phone technology

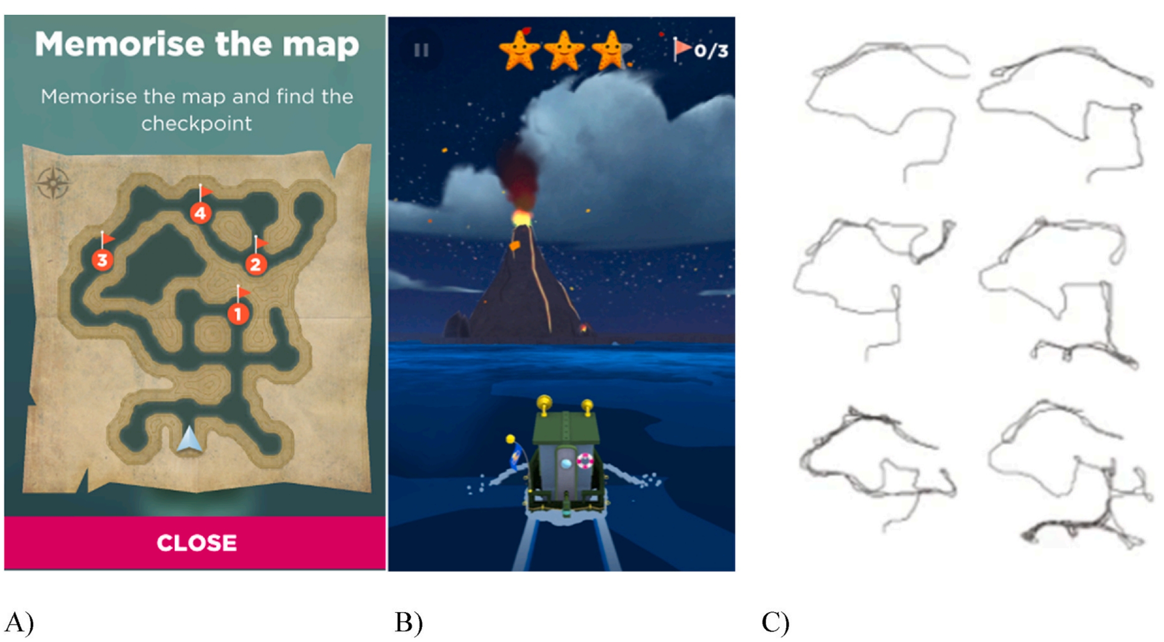

Fig. 1. Outline of the wayfinding task. (A) At the start of each level presented participants were presented with a map indicating the goals which they had to navigate to in the order indicated, where '1' indicates goal number 1 etc. (the map from level 42 is shown as an example). Level 1 (not shown) provided one goal and a simple river to reach the goal as training. (B) Participants selected to close the map by pressing 'close', at which point the participant had to translate from an allocentric (survey) perspective into a third-person egocentric (route) perspective in order to start navigating to the goals. Third-person view of the environment is shown where the participant tapped left or right of the boat to steer it. (C) Examples of individual player trajectories (level 42) from the start location to the final goal. Trajectories are ordered by performance, with the top left providing the best performance (shortest trajectory length), through to bottom right who has the worst performance (longest trajectory length). Adapted from Coutrot et al. (2018).

is related to both video game experience and GPS use (many people use GPS-based apps on their phone), we also included hours of weekly phone use as a covariate.

Secondly, we conducted a variation of the first model without including weekly hours of video gaming as a predictor variable, in order to determine whether gender was significantly associated with navigation performance when video game experience was not accounted for.

Thirdly, as a supplementary analysis, we conducted a variation of the first model to explore whether there was an effect of video games playing on the weighted score from the tutorial level (level 1) which does not test navigation, but might be mastered more efficiently by those familiar with mobile-based game interfaces (Supplementary Table S5). This was motivated by the fact that SHQ is itself a video game, Fourthly, as a supplementary analysis, we conducted a variation of the first model where we grouped those who reported most commonly playing role-playing-, action- or simulation-based video games as 'navigation-related' gamers and those playing other genres most commonly as 'non-navigation-related' gamers in accordance with classifications proposed by previous research (Dindar, 2018; Leonhardt & Overå, 2021; Lucas & Sherry, 2004; McLaren-Gradinaru et al., 2023; Quaiser-Pohl, Geiser, & Lehmann, 2006). This was to determine whether video game genre could account for possible associations between video game experience and wayfinding ability.

As a check for multicollinearity, we calculated the adjusted generalised variance inflation factor (*GVIF*) value for each predictor variable included in the model, which is equal to the Variance Inflation Factor (*VIF*) values for each predictor variable divided by the number of categories for each categorical predictor variable: $GVIF = VIF\hat{}[1/(2*df)]$. The *GVIF* value was scaled to account for differences in the number of degrees of freedom for each of the predictor variables in the model, producing an adjusted *GVIF* value: adjusted $GVIF = GVIF\hat{}[1/(2*df)]$. For cases where a model contained a categorical variable with more than two categories, the $GVIF\hat{}[1/(2*df)]$ value is displayed for each predictor variable in the model. In cases where the model contains no predictor variable with more than two categories, the *VIF* value is displayed. A *VIF* or $GVIF\hat{}[1/(2*df)]$ value of <5 indicates that multicollinearity is not a concern (Fox & Monette, 1992; Kim, 2019).

Post-hoc t-tests bonferroni-corrected for multiple comparisons to control for type 1 errors were carried out where main effects and interactions were significant.

3. Results

3.1. Multiple linear regression analysis

In this analysis, GPS reliance score, hours of video game use per week were the key variables of interest, whilst age, gender and hours of phone use per week were covariates. Interactions between gender and both average GPS reliance score and hours of video game use per week on all devices were included in the model. *VIF* values indicated that multicollinearity was not a concern (Supplementary Table S1). A summary of basic descriptive statistics for the variables included in the model is shown in Table 1.

The outputs from the multiple linear regression model are as follows:

3.2. Main variables of interest

3.2.1. Hours of weekly video gaming on all devices

As predicted, hours per week video game use on all devices per week was significantly associated with wayfinding distance ($\beta = -0.12$, $f2 = 0.04$, $p < 0.001$, $CI = [-0.17, -0.06]$) (Table 2 and Fig. 2). Post-hoc t-tests revealed that those playing≥10 h of video games per week on all devices were significantly better navigators than both those playing≥5 h but <10 h and those playing <5 h per week, as indicated by the shorter wayfinding distance in the former group ($p < 0.017$, bonferroni-corrected with 3 comparisons).

Table 2
Output of the model predicting weighted wayfinding distance based on GPS reliance and video game experience.

Variable	β	95% CI	t	p	sig	f2
(Intercept)	−0.20	[-0.28, −0.13]	−5.46	**<0.001**	***	
Age	0.10	[0.07, 0.14]	5.65	**<0.001**	***	0.03
Male gender	0.10	[0.02, 0.17]	2.40	**0.017**	*	0.05
Average GPS reliance score	−0.02	[-0.07, 0.03]	−0.83	0.408		<0.01
Weekly hours of phone use	0.06	[0.02, 0.09]	3.23	**0.001**	**	0.01
Weekly hours of video gaming on all devices	−0.10	[-0.15, −0.05]	−3.74	**<0.001**	***	0.04
Highest education level achieved	0.04	[-0.03, 0.11]	1.04	0.297		<0.01
Gender*Average GPS reliance score	0.08	[0.01, 0.15]	2.17	**0.030**	*	<0.01
Gender*Weekly hours of video gaming on all devices	−0.03	[-0.11, 0.04]	−0.84	0.402		<0.01
Average GPS reliance score*Weekly hours of video gaming on all devices	0.03	[-0.01, 0.06]	1.51	0.131		<0.01

P-values for the significant associations are highlighted in bold.

3.2.2. Reliance on GPS

Contrary to our hypotheses, average GPS reliance score was not significantly associated with wayfinding distance ($\beta = -0.03$, $f2 = <0.01$, $p = 0.350$, $CI = [-0.08, 0.03]$) (Table 2 and Fig. 2). Moreover the interaction between average GPS reliance score and gender did not reach significance ($\beta = 0.07$, $f2 = <0.01$, $p = 0.08$, $CI = [-0.01, 0.15]$). Table 2 and Fig. 2 indicate that the non-effect of GPS held for both men and women.

3.3. Exploratory analysis

3.3.1. Gender when not accounting for hours of weekly video gaming on all devices

We conducted a second multiple linear regression model using the same predictor variables as in the model above except that we removed video game experience as a predictor variable. When we removed video game experience as a predictor variable, gender remained significantly associated with wayfinding distance ($\beta = 0.17$, $f2 = 0.03$, $p < 0.001$, $CI = [0.09, 0.25]$) (Table 3).

3.3.2. Gender x reliance on GPS

There was a significant but small effect of the interaction between gender and GPS reliance on weighted wayfinding distance ($\beta = 0.08$, $f2 = <0.01$, $p = 0.030$, $CI = [0.01, 0.15]$) (Table 2). It indicates that the association between reliance on GPS and weighted wayfinding distance was significantly stronger in females.

3.3.2.1. Tutorial level 1 wayfinding performance. When examining wayfinding performance in tutorial level 1, there was no significant association between video game experience and weighted wayfinding distance ($\beta = -0.03$, $f2 = <0.01$, $p = 0.550$, $CI = [-0.12, 0.06]$) (Supplementary Table S5).

3.3.3. Video game genre

When we conducted a model using video game genre as a predictor variable, we did not find a significant association between video game genre and weighted wayfinding distance ($\beta = 0.02$, $f2 = <0.01$, $p = 0.579$, $CI = [-0.05, 0.09]$) (Supplementary Table S12).

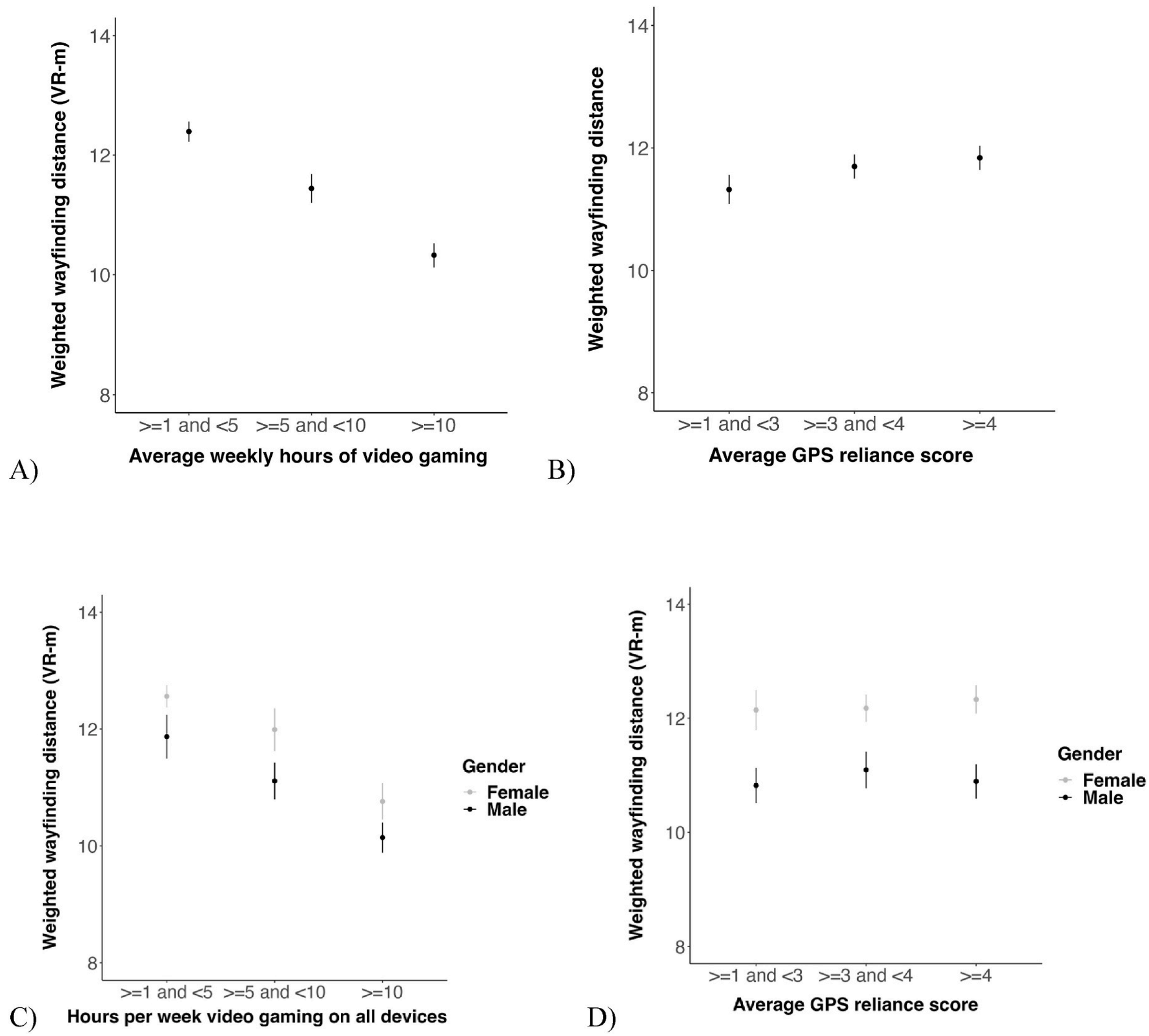

Fig. 2. Associations between both weekly hours of video gaming and average GPS reliance scale scores and weighted wayfinding distance across gender and in men and women separately. (A-B) Data points represent the mean wayfinding distance across game levels across participants. VR-m = virtual reality metres. Whilst video gaming experience was significantly associated with weighted wayfinding distance, where a greater number of hours of weekly video gaming on all devices was associated with a shorter wayfinding distance (i.e., better wayfinding performance), reliance on GPS was not.

Table 3
Output of the model predicting weighted wayfinding distance without including video game experience as a predictor variable.

Variable	*β*	*95% CI*	*t*	*p*	sig	*f2*
(Intercept)	−0.27	[-0.34, −0.20]	−7.73	<0.01	***	
Age	0.11	[0.07, 0.14]	5.65	**<0.01**	***	0.03
Male gender	0.19	[0.12, 0.27]	5.27	**<0.01**	***	0.05
Average GPS reliance score	−0.01	[-0.06, 0.04]	−0.35	0.72		<0.01
Weekly hours of phone use	0.04	[0.01, 0.08]	2.42	**0.02**	*	0.01
Highest education level achieved	0.07	[-0.01, 0.14]	1.75	0.08	.	<0.01
Gender*Average GPS reliance score	0.05	[-0.02, 0.12]	1.51	0.13		<0.01

P-values for the significant associations are highlighted in bold.

3.4. Covariates

Please see Supplementary Table S1A-D for visualisations of the associations between each of the covariates with wayfinding distance.

4. Discussion

Using a virtual navigation test embedded in a mobile-based video game and a set of questionnaires, we examined whether reported reliance on GPS and/or reported video games playing was associated with navigation performance. We found an association between video games playing and wayfinding distance, consistent with our predictions. However, we found no significant association between average GPS reliance scores and wayfinding distance, contrary to our hypothesis and in contrast with previous findings (e.g., Dahmani & Bohbot, 2020; He & Hegarty, 2020). We discuss these key results in turn.

Confirming our hypothesis, there was a significant association between hours of video game use and navigation performance, such that more hours of video gaming was associated with better navigation performance. This extends previous research by focusing on wayfinding ability at a large-scale and corroborates previous findings demonstrating an association between greater hours of playing video games and improved spatial cognition (Feng et al., 2007; Green & Bavelier, 2003; Liu et al., 2020; Mclaren-Gradinaru et al., 2020; Murias et al., 2016). It is possible that this association was driven by the fact that those playing video games with a navigational component were able to train their navigation skills whilst gaming, as suggested by previous studies showing that men tend to play action-, role-play- and simulation-based video games which are more likely to have a navigational component (Dindar, 2018; Leonhardt & Overå, 2021; Quaiser-Pohl et al., 2006). However, our finding that video game genre had no significant association with wayfinding ability (Supplementary Table S12) does not support this hypothesis. Rather, it may be that video gaming provides a general benefit irrespective of the genre, such as training attentional processes. Other studies have also found gender differences in attitudes towards- and reasons for playing video games (Dindar, 2018; Lucas & Sherry, 2004; Ogletree & Drake, 2007), which were not investigated here but may have also accounted for our findings.

Contrarory to our hypothesis, we did not find a significant association between reliance on GPS and wayfinding performance, which may be explained by several factors. Although our study used the same GPS reliance scale as that used by Dahmani & Bohbot, 2020, and used participants within a similar age range, their navigation task differed from ours. They had participants remember the locations of objects within a radial arm maze. In our study, participants had to remember the locations of a series of checkpoints from a one-shot encoding of a cartographic map and then navigate to these checkpoints without the map available. Thus, differences in the cognitive abilities required by the experimental task may have accounted for differences in findings. Dahmani & Bohbot, 2020 also found that a greater reliance on GPS was associated with less use of a landmark strategy during a radial arm maze task. Thus, we might have expected an association between reliance on GPS and navigation performance in SHQ because we have previously shown that landmark use in SHQ radial mazes is associated with good navigation (Garg et al., 2023; West et al., 2023). However, the association between reliance on GPS and wayfinding distance remained non-significant when we accounted for navigation strategies used (Supplementary Table S7), not supporting this hypothesis. He and Hegarty (2020) used SBSOD as a proxy for navigation, but Garg et al. (2023) showed that there was no significant association between scores on the Santa Barbara Sense of Direction Scale (SBSOD) and SHQ wayfinding performance. This may help explain why we did not find a significant association between reliance on GPS and navigation performance, whilst He & Hegarty, 2020 did.

Interestingly, not all studies have shown that reliance on GPS is detrimental to navigation performance (Brugger et al., 2019; Ercevik Somnez & Erinsel Onder, 2019; Huston & Hamburger., 2023; Kelly et al., 2022; Leshed et al., 2008; Wunderlich et al., 2022; Yan et al., 2022). For example, studies have suggested that the way one interacts with GPS-assisted devices may be an important factor in determining whether they aid one's navigation ability, where actively engaging with the device has been shown to result in improved navigation performance than doing so passively (Brugger et al., 2019; Huston & Hamburger, 2023; Richter et al., 2010; Topete et al., 2024). GPS-assisted devices have also been shown to enrich one's ability to learn to navigate new environments, both through the formation of mental imagery and through creating more meaningful experiences for the user (Ercevik Somnez & Erinsel Onder, 2019; Leshed et al., 2008). Thus, the association between reliance on GPS and wayfinding performance may differ based on how one interacts with GPS-assisted devices and experiences they encounter when using such devices.

We found that the significant association between gender and wayfinding performance was weaker when accounting for video game experience, as indicated by the smaller effect size. This finding is partially consistent with a previous study where men lost their advantage in mental rotation ability whilst women gained a small advantage in spatial perspective taking ability when accounting for previous video game experience (McLaren-Gradinaru et al., 2023). A key factor that may have contributed to this significant gender difference in wayfinding performance, even when accounting for gaming experience, is stereotyped beliefs about navigation ability (Walkowiak et al., 2023). Given that women show similar mental rotation and perspective-taking performance to men when they are led to believe they are better than men (Moè, 2009; Tarampi et al., 2016), it is plausible that women performed worse than men as a result of having lower self-efficacy in their navigation abilities (Miola et al., 2023). A second key factor that may have also contributed to this finding is one's choice of navigation strategy. For example, women show better performance than men when using a landmark-based strategy (Harris, Scheuringer, & Pletzer, 2019; Munion et al., 2019), and show a slower decline in landmark-based strategies during spatial memory tasks (West et al., 2023). However, when we included navigation strategy questionnaire scores in an additional model (Supplementary Table S7), the output remained unchanged. Thus we do not find evidence that choice of navigation strategy strongly accounts for gender differences in navigation ability in our task. This is consistent with recent evidence that the presence of landmarks did not show gender-specific effects on wayfinding performance in SHQ (Yesiltepe et al., 2023). Thirdly, differences in spatial memory performance may have also accounted for such findings, where greater spatial memory performance has been found in men (Persson et al., 2019). Given that navigation strategy use, spatial memory performance and self-efficacy have been shown to be influenced by the perspective one takes when navigating (Harris et al., 2019; Iriye & St. Jacques, 2021; Moè, 2009), it is plausible that performance on our wayfinding performance - which involves switching between different perspectives - may have been influenced by these factors.

We also considered whether our observation of the beneficial effects of video games playing was because our navigation test was in itself a video game. Future research will be useful to confirm whether real-world navigation will be enhanced by video game playing. Nonetheless, to explore this topic in the current data we examined the tutorial level (Level 1 of SHQ, which requires minimal navigation), where we reasoned that participants who play a significant amount of video games should have an advantage by taking shorter direct paths to the visible goal (see Supplementary Table S5) if their navigation advantage arose purely from their familiarity with interfaces/controllers. However, we found no evidence for this. Rather, it appears the advantage associated with video games playing is specific to the cognitively demanding navigation tasks in SHQ that require orientation and spatial memory. This mirrors prior research with SHQ, where we found that the tutorial level (level 1 of SHQ) was not predictive of real-world navigation in London or Paris, while SHQ levels that require memorising the map and navigating to the hidden multiple goals were related to real-world navigation (Coutrot et al., 2019). Although replicating these findings in real-world situations is an important focus for future research, our results show that better navigation performance on SHQ is not likely to be purely an effect of familiarity with interfaces/controllers. Finally, given that our main hypothesis relating to the association between video gaming experience and navigation ability focused on a single question (i.e., 'How many hours of video gaming do you engage in per week?), further studies should use on a wider range of questions that explore different facets related to video gaming experiences to better understand the relationship between video gaming experience and navigation ability. Such questions should include those relating to the frequency, context (e.g., gaming socially or non-socially) and one's motives for video gaming which may influence the relationship between video gaming experience and navigation ability (Dindar, 2018; Lucas & Sherry, 2004; McLaren-Gradinaru et al., 2023; Ogletree & Drake, 2007).

4.1. Limitations and future directions

While our study allowed assessment of over 800 participants on an ecologically valid (Coutrot et al., 2019) and reliable cognitive test of navigation (Coughlan et al., 2019), there are a number limitations to consider that future studies could address. It would be useful to explore direct metrics for video game use and reliance on GPS from device data, rather than self-estimates. Although we conducted psychometric analyses for our current measures, self-estimates can still be biassed, with studies showing different degrees of correlations with self-rating scores and performance (e.g. Garg et al., 2023). Age and the impact of different cultures may well modulate the potential impact that reliance on GPS may have on navigation, thus testing participants in a broader range of countries and age ranges would be beneficial (Walkowiak et al., 2023). Additionally, despite SHQ being an ecologically valid and reliable cognitive test of navigation, we only focused on 4 game levels in the current study, which may have limited the generalisability of our findings. The 4 game levels we used here also had very few landmarks, which may have also facilitated the male advantage we found here (see Harris et al., 2019). Moreover, the SHQ wayfinding task used here favours the use of a survey (allocentric) spatial navigation strategy - seeing a top-down view of the environment before navigating, which has traditionally been used as an explanation for a navigation advantage in men (Munion et al., 2019). Finally, the use of a video game to assess the association between video game experience and wayfinding ability may have partly accounted for the significant association between video game experience and wayfinding ability. Accordingly, future studies would also benefit from using a broader range of virtual navigation and spatial memory tests that extend to real-world environments and do not involve gamification (Coutrot et al., 2019; He et al., 2021; Hill et al., 2023; Howard et al., 2014; Javadi et al., 2019; Patai & Spiers, 2021), incorporating analysis of path choices that estimate the extent to which participants are using certain strategies or heuristics for navigation (de Cothi et al., 2022; Lancia et al., 2023, Mcelhinney et al., 2022).

5. Conclusion

Overall, our findings suggest that greater engagement in certain activities, such as playing video games, may be associated with a stronger wayfinding ability. Accordingly, our findings highlight the need for future intervention-based research to investigate whether there is a causal relationship between video gaming experience and wayfinding ability, including whether cognitive processes related to navigation may be exercised by playing video games and whether the specific genre of video game one plays may be important in this relationship, as suggested by the literature. Future studies should also determine whether the way one interacts with GPS-assisted devices may be important in- and causally related to navigation ability. From a clinical perspective, understanding how exercising cognitive abilities associated with navigation through engaging in daily activities may provide a fruitful path to determining the factors that may reduce one's risk of cognitive decline.

Data availability

https://osf.io/7nqw6/?view_only=6af022f2a7064d4d8a7e586913a1f157https://shqdata.z6.web.core.windows.net/ A dataset containing the preprocessed trajectory lengths and demographic information is available at https://osf.io/fqxzv/. We also set up a portal where researchers can invite a targeted group of participants to play SHQ and generate data about their spatial navigation capabilities. Those invited to play the game will be sent a unique participant key, generated by the SHQ system according to the criteria and requirements of a specific project decided by the experimenter. https://seaheroquest.alzheimersresearchuk.org/. Access to the portal will be granted for non-commercial purposes. Future publications based on this dataset should add 'Sea Hero Quest Project' as a co-author.

Code availability

The code used to produce this data is accessible at: https://osf.io/fqxzv/?view_only=ffc994fe850e4bb981fd39df0e843d80.

CRediT authorship contribution statement

Emre Yavuz: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Chuanxiuyue He:** Conceptualization, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review & editing. **Christoffer J. Gahnstrom:** Data curation, Writing – review & editing. **Sarah Goodroe:** Data curation. **Antoine Coutrot:** Funding acquisition, Methodology, Writing – review & editing. **Michael Hornberger:** Writing – review & editing, Software, Funding acquisition, Data curation. **Mary Hegarty:** Writing – review & editing, Visualization, Supervision, Methodology, Investigation, Data curation, Conceptualization. **Hugo J. Spiers:** Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization, Visualization, Writing – review & editing.

Declaration of competing interest

The authors of this manuscript declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2024.102296.

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