The Effects of Navigation Assistance on Spatial Learning and Performance in a 3D Game

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ABSTRACT
Navigation in 3D game environments is often difficult for novices, who may get lost and be unable to reach game objectives. Many games provide navigation assistance (e.g., mini-maps, directional markers, or glowing trails); however, there is a risk that players will become reliant on an aid and fail to develop a mental model of the map. To investigate, we carried out two online studies in which people carried out training tasks with varying navigation assistance. After training, they navigated the map with assistance turned off. In both studies, we found that assistance improved training performance, but found no harmful effect of assistance on performance after it was removed, even when comparing between those who received glowing trails to follow and those who received no assistance. We show that navigation assistance in 3D games is effective, and that it does not necessarily harm development of a novice's spatial learning.

Author Keywords
Game navigation; navigation aids; guidance hypothesis.

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K.8.0 [Personal Computing]: General - Games.

INTRODUCTION
There are many skill differences between novices and experts in 3D games, including targeting, evading enemy attacks, understanding weapon capabilities, and the ability to memorize and navigate the game map [27,48]. Map knowledge – knowing one's own location as well as knowing game locations and routes – can dramatically affect play experience: whereas experts quickly learn where resources and enemies are located [43], novices find themselves continually lost and unable to get to objectives.

Spatial abilities in games are of particular interest because unlike many game skills, learning and navigating 3D environments is something that people do in the real world throughout their lives. Even though there are individual differences in spatial ability, most people are fully able to function in the environments around them, and can easily find their way through houses, office buildings, or shopping centres. This does not appear to be the case in 3D games: Several researchers have noted the difficulty of navigating virtual environments [15,16], and there are many examples of novice players discussing difficulties with navigation, or videos making fun of their poor navigational skills. For example, a player of *Final Fantasy Online* posted in a forum:

> **Noob, Lost, Cannot find my way around the map to the point of AHHHHHHH!!!** I am super frustrated. I am a noob to the game. I am somewhere on some steps... I can get to all the levels and outside but I cannot find the Drowning Wench. […] Once you stop laughing at how much of a moron I am for not being able to find my way out of a paper bag could someone please give me some tips or something. (forum.square-enix.com/ffxiv/threads/90497)

Problems with game navigation – that is, getting lost or not knowing how to get to an objective – can be extremely frustrating, and may contribute to a novice player's decision to quit the game. To reduce navigational difficulty, some games add directional assistance to the game environment, such as markers telling the player where to go (Figure 1), or routes drawn on the game map (Figure 2). However, these assists have one significant limitation – they only work when the desired destination is well known. There are many situations in which a player needs to adapt to changing conditions in the game and stray from the well-marked path: for example, to find an alternate route that flanks an enemy, or to look for treasure in the environment. In fact, wayfinding itself can be a compelling challenge for many players [38], and some even feel that the joy of discovery is stolen from them when an assist led them to that discovery [12].

Although providing novices with assistance can improve early performance and experience, designers may be setting players up to fail later on. There is a concern that a player will become reliant on an aid, and when they are eventually required to navigate on their own (e.g., to play competitively), they will be unable to do so. This phenomenon of players relying on external feedback is known as the *guidance hypothesis* [40,41], which suggests that greater effort during training (i.e., *intentional* learning) will lead to better retention and understanding [18].

In contrast to the guidance hypothesis, however, is research suggesting that spatial knowledge in 3D environments can be gained through *incidental* learning [2,4,23]. Incidental learning occurs simply through exposure to an environment

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– for example, people may learn the layout of a building even if they are being led by a guide. This natural ability to learn about an environment may arise because an understanding of our surroundings was critical for the survival of early humans. There is debate about whether location learning can occur as an incidental process, however, and there are studies that point to problems in spatial learning caused by navigation aids such as GPS (e.g., [6,26,33]).

These competing theories about location learning mean that it is difficult to predict the effects of navigational assistance techniques in games. To determine both the benefits and risks of navigation assistance in 3D games, we carried out two studies in which novices completed several route-finding tasks with different forms of navigation aid, and then completed test routes without any assistance. The training tasks used one of three assistance levels: *no assistance*, *moderate assistance* (a mini-map and pop-up map with the player's current location), or *strong assistance* (a path drawn on the ground of the game world itself). The testing routes required novices to navigate un-aided to a particular landmark. Both studies used the same testing and training routes, and the same two real game environments: the "Gold Rush" map from *Enemy Territory* [42], and the "Furious Heights" map from *Quake Live* [25].

In the first study, participants completed sixteen training routes, then eight test routes, all in the same session. In the second study, participants completed sixteen routes in each of three sessions on three successive days, as well as eight test routes on the third day. In addition to the in-game navigation test, we asked participants questions to assess their knowledge of landmarks, routes, and distances on the two game maps; and we also asked them to rate their play experience after training and after testing.

Our goal in both studies was to determine whether having more assistance during training would result in poorer navigation performance and knowledge during testing (when assistance was removed). The results of both studies were surprising – in neither case did our findings agree with the predictions of the guidance hypothesis:

- Navigation assistance helped substantially when it was present: in both studies, having more assistance allowed participants to complete significantly more routes, and to complete them in significantly less time.
- There were no performance differences in testing: despite the strong effects in training, there were no significant differences in performance on the test tasks – including the number of test routes completed, the distance travelled, or the completion time – regardless of whether or not people had assistance during training.
- Subjective responses mirrored performance results: the presence of navigation assistance significantly reduced perception of effort, frustration, and mental demand. When the assistance was taken away in testing, these differences disappeared.

Our findings confirm that navigation assists substantially help novices, and adds to evidence [20] that early guidance does not necessarily hinder performance when taken away (even with strong assistance such as glowing trails). Our results can be used by game designers in several ways: first, designers should be aware of the difficulties that novices have in learning 3D game environments; second, designers can substantially improve novices' initial play experience with navigation assistance; third, navigation assistance can be used as a player-balancing mechanism for social-play situations; and fourth, taking navigation assistance away will not necessarily result in the player becoming lost.

RELATED WORK

Navigation in Real and Virtual Environments

A wide variety of research has been carried out to investigate the ways that humans learn and perform navigation in real-world environments – for example, researchers have looked at the development of spatial knowledge in children (e.g., [21]), sex differences in navigation (e.g., [9,32]), and theoretical models for navigation (e.g., [11]). One major focus in navigation research is on *wayfinding*, the process by which people orient themselves to an environment and move from place to place. Early work identified three kinds of knowledge that are important for wayfinding, and that are associated with increasing spatial understanding [45–47]:

- *Landmark knowledge* involves remembering specific objects or settings in an environment – such as a statue or a building in a city centre.
- *Route knowledge* is understanding how to navigate between specific locations, and the actions required to reproduce a specific path between them. Route knowledge often builds on landmark knowledge (e.g., by linking different landmarks together).
- *Survey knowledge* is a map-like mental representation of an environment, and is the highest form of spatial understanding. Survey knowledge allows people to navigate skillfully, estimate relative distances, and choose alternate routes to objectives.

There are two ways in which people can gain this spatial understanding of an environment [15]. First, people learn through direct exposure to their surroundings – that is, simply being in an environment and moving through it. Second, external information sources such as maps provide other forms of spatial learning. When used in an actual navigation task, maps require that users identify their own location on the map, and then translate orientations, directions, and distances from the map representation to the actual environment.

Researchers have also studied a variety of navigational tools and aids in real-world wayfinding. The most common tool is the map, and researchers have looked at several aspects of map use, such as the differences between "track-up" and "north-up" orientations [3]. Recent research has also looked at the effects of guidance systems such as GPS, and has found that people can become overly focused on the directions provided by external guidance, hindering the development of their spatial knowledge (e.g., [6,26,33]).

Navigation in virtual environments has also been extensively studied. One main interest is in whether virtual environments can be used as training simulations for real-world navigation [51], and whether spatial knowledge and wayfinding ability transfer to real environments. Researchers have also identified that navigational difficulties are common in virtual environments (e.g., [15,28]): "Virtual world navigators may wander aimlessly when attempting to find a place for the first time. They may then have difficulty relocating places recently visited. They are often unable to grasp the overall topological structure of the space" ([15], p. 166).

To combat these difficulties, previous work has also looked at a variety of navigational aids. The value of landmarks has led researchers to consider the idea of allowing users to place visual markers, having the system create a visual trail showing where users have been, or having a fixed marker to provide a consistent indication of north [15,16]. Results with these forms of assistance are mixed, however: adding a simple compass did not substantially improve navigation performance [17], and trails can quickly clutter an environment. To our knowledge, no studies have looked at the effects of navigation assistance on spatial performance once the assistance has been removed.

Incidental vs. Intentional Spatial Learning

A continuing debate concerns the relationship between spatial knowledge acquisition and intentionality. Studies indicate that at least some aspects of location learning occur automatically [2,23]. For example, one study showed that recall of word locations was unaffected by the difficulty of a concurrent task [2]. Other work, however, shows the importance of intention; studies have shown that when people focused their attention on a route through a building, they were better able to draw a map of that path [4], and that even long experience with an environment may still result in poor survey knowledge [8].

Similarly, Ehret [18] suggests that the amount of attention, repetition, and practice during training will affect the degree to which an object's location can later be retrieved from memory. Ehret suggests that because explicitly remembering locations requires effort, people will choose a lower-cost strategy when possible, impairing their learning. This phenomenon is related to the guidance hypothesis and effort-retrieval hypothesis, described further below.

Navigational Assistance in Games

From subtle signs or arrows, to obvious glowing trails, many games feature navigational aids or assistance. Two common navigational assists are compasses and mini-maps [38]. Both are used to display locational information to the player. An example is the quest marker [38,54] – icons that indicate the start, end, or intermediate goal of a quest. For example, *Skyrim* [5] (Figure 1) includes a compass at the top of the screen with markers for selected quests and icons for points of interest. Mini-maps are used similarly: *Counter-Strike: Global Offensive*'s [24] mini-map shows nearby teammates and the location of objectives.

A stronger aid that is found in games is a highlighted trail in the environment. The effect is often implemented as a smoke or particle trail along the recommended path. For example, *Fable II* [34,44] (Figure 2) and *Neverwinter* [13] have particle trails which can be turned on or off through the user interface. In other cases, the trail may be implemented diegetically: in *Skyrim*, magic users have access to a "clairvoyance" [5] spell that temporarily highlights the route to a quest marker with a smoke trail.

Figure 1. The quest marker on *Skyrim*'s compass display, showing the direction to the next objective.

Figure 2. Glowing "breadcrumb trail" in *Fable II*, showing the path to the start of the quest (or the next objective).

Skill Development in Games

Games have gained a reputation as powerful learning tools; they are able to transform novices into experts through an engaging, motivating, and enjoyable experience [19,31]. Many theories apply to learning in games. We describe Kiili's experiential gaming model, the guidance hypothesis, and the retrieval effort hypothesis.

Kiili's experiential gaming model is based on experiential learning theory [30], flow theory [10,14], and the zone of proximal development [49]. In *experiential learning theory,* a person forms a prediction based on their prior experiences and then tests those predictions on new experiences. Games provide many opportunities for players to test their ideas and predictions [19]. *Flow theory* describes a state in which one becomes so immersed in an experience that they notice nothing outside of that experience. Well-designed games are able to keep players in the flow state for long periods of time by providing challenges that are well-matched to the player's ability [19,29,31]. The *zone of proximal development* describes what a learner can accomplish if they are given some guidance. Often, the systems within a game can provide that guidance, scaffolding a player to overcome a challenge just outside their current skill level [31].

Kiili incorporates ideas from these three theories to form his experiential gaming model [29]. As it has been shown that being in the flow state benefits learning [52], Kiili proposes that the flow state can be extended with the zone of proximal development – if a player's ability is scaffolded so that they can complete challenges just outside of their ability, maximum learning will occur. Kiili's model is based on continual re-learning, and includes two phases. In the *ideation* phase, the learner generates ideas and potential solutions while in the *experience* phase, the learner tests their ideas while attempting to overcome in-game challenges. After testing, the learner can then incorporate their new experiences and generate new ideas.

The *guidance hypothesis* refers to the phenomenon where a learner starts to rely on extrinsic feedback provided by a system. The type of feedback which leads to this phenomenon is Knowledge of Results (KR) [40]. KR refers to extrinsic feedback indicating task success in response to a learner's actions [41]. A few researchers have studied whether assistance systems in games result in reliance on the assistance. For example, Gutwin et al. [20] investigated whether providing players with aim assistance in a first-person shooter (FPS) would hinder aiming ability without the assist, or affect their ability to learn other FPS skills. They found that players were not hindered in skill development for either skill when aim assist was present – in opposition to what the guidance hypothesis suggests.

The *retrieval effort hypothesis* refers to the relationship between the amount of effort involved in memory retrieval and the development of memory: "given that retrieval is successful, more difficult retrievals are better for memory than less difficult retrievals" [39]. In other words, increased effort when trying to remember should lead to a better memory of the retrieved information. This difficulty can be operationalized in many different ways, such as spacing out the time between retrievals [39], or making users use less representative symbols in a mental mapping between symbol and colour [18].

STUDY 1

We conducted an online experiment to explore whether the amount of assistance provided to a player when navigating an unfamiliar environment would affect route-finding ability and player experience, both when the assistance was present and after it was removed.

Study 1 Experimental Design

We designed and implemented a system that allowed online participants to navigate 3D environments between defined start and end points. The system could vary the amount of navigation assistance provided to the player. We investigated three levels of assistance, and implemented these in two environments from 3D first-person shooter (FPS) games.

Navigation Task

Participants were asked to navigate from a starting position to an end location in a 3D environment. The game environment and the navigation tasks were implemented using the Unity game engine and were deployed online as a browser-based WebGL game displayed on a computer monitor. For each task (also referred to as a route), participants were placed at a predefined starting point, and instructed to move to a location indicated on the map.

Both training and testing phases involved navigating a 3D environment, but there were three different interfaces used during the training phase that provided different amounts of navigation assistance. These interfaces included several elements (Figure 3): a mini-map in the top-right corner of the screen, a full-screen map that was accessed by pressing the M key, and a route path that was displayed in the game world. In training tasks, the destination location was indicated with a flag on the maps and in the environment. In testing tasks, none of the three assists were used, and the destination was indicated at the start of the task as an image of an in-game landmark (such as a tank, bars of gold, or an in-game powerup) that the player needed to reach. This destination was also marked in the environment with a flag. To ensure that any spatial learning was acquired incidentally, there was no prior indication before or during training that participants would be tested on their spatial knowledge. In both training and testing, participants had to touch the flag to complete the task. All tasks had a 90-second time limit, after which the system would move to the next route (optimal times to traverse the routes ranged from 5-25s).

Assistance Levels (Training Phase)

The assistance groups were designed to vary the amount of navigation effort required by the participant. The system had three assistance levels, from no assistance to strong assistance, as shown in Figure 3.

No Assistance. With no assistance, the player saw the normal first-person view, and had access to a full-screen pop-up map (invoked with the M key) that showed the target destination. In this condition, participants had to identify their own position on the map, plan a route to the destination, and translate directions and distances from the map view to the first-person environment.

Moderate Assistance. With moderate assistance, the interface showed an always-on mini-map in the top right corner of the screen. The pop-up map was also available. In addition to the target icon (a red flag), both maps included an icon indicating the player's current location and direction (similar to the pin icon used in Google Maps). In this condition, participants could see their dynamic progress on the map views – and if they focused on the map, there was less of a requirement to translate to the first-person view.

Strong Assistance. The strong assistance interface provided the same mini-map and pop-up map as described above, but additionally showed the path to the destination with a solid white line permanently drawn in the game environment. The line was a guide only – players could take any route they wanted. This visual effect is similar to the navigational aids

Figure 3. Left to right: Strong assist, moderate assist, and no assist, and testing UI (showing the "Gold Rush" map).

used in several commercial games (as discussed above). In this condition, players had to expend far less effort than with the other interfaces – they did not have to identify their location or plan a route, and could simply follow the white line to the destination.

3D Game Environments

We used environments from two commercial 3D first-person shooter games. From *Wolfenstein: Enemy Territory*, we used the map "Gold Rush," and from *Quake Live*, we used the map "Furious Heights." These maps were extracted from the original games and recreated in Unity.

"Gold Rush" (Figure 3) is set in a fictional town in northern Africa, and most of the routes in the map take place outside. The town has a variety of streets, walls, buildings, passages, plazas, and staircases. There are several naturalistic landmarks such as palm trees in a town square, vehicles including carts and tanks, and multi-story towers.

"Furious Heights" (Figure 4) is set in a fictional multi-level castle, and all of the routes take place indoors. The castle has multiple distinct floors, and the most obvious landmarks in the map are artificial game objects (e.g., a glowing yellow first-aid symbol) that float above the floor. This environment also features two special navigation-related game mechanics: teleporters and jump pads. Both teleporters and jump pads allow players to travel to a higher floor, but are not required to travel through the environment.

Study 1 Procedure

At the start of the study, participants were told that the study would use WebGL to render 3D environments, and that they would need a relatively fast computer to participate. They were then asked to provide informed consent, and continued through the three phases described below.

Navigation Tutorial and Random Group Assignment. Participants were instructed to complete a simple navigation task in a separate tutorial level (not used in the rest of the study). The task had them walk down a hallway, jump over a small gap, travel through a teleporter, take a jump pad to a higher level, and finally, touch a flag to proceed. This tutorial was intended to give participants a chance to check their system's performance before getting too far into the experiment, and to introduce them to the controls they would use to navigate the virtual environment and the gameplay mechanics of the teleporter and the jump pad. After the tutorial, participants completed demographic and personality trait questionnaires. They were then randomly assigned to one of three assistance groups, and one of two orders.

Training Phase. Depending on their order group, participants started with either the Furious Heights map or the Gold Rush map. They carried out eight different route tasks (as described above). After completing the eight routes, participants completed a questionnaire about their subjective experiences. This training procedure was then repeated for the second map for their order group (for a total of 16 routes).

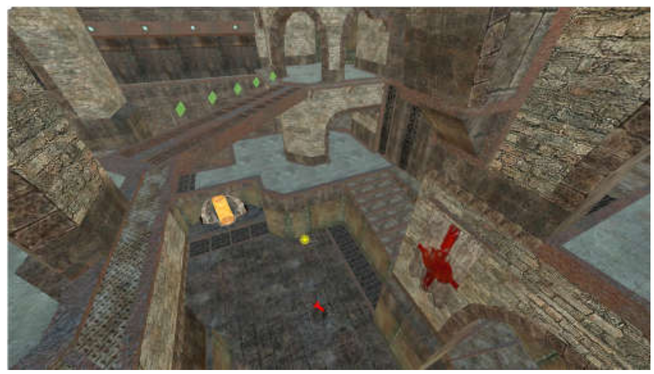

Figure 4. "Furious Heights" environment from *Quake Live*.

Testing Phase. After completing training routes and experience questionnaires in both maps, participants moved to a testing phase that involved questions about their spatial knowledge, and four additional route tasks in each map. First, the spatial-knowledge questions asked participants to locate four landmarks and three scenes on a 2D map that was similar to the pop-up map used in the training tasks, but with no marked icons. The landmarks and scenes had all been seen previously in the training phase. Participants answered the spatial-knowledge questions for both maps, in the same order as for training. Second, participants carried out four route tasks in each map: they were shown a picture of a landmark and instructed to go to it as directly as possible, but with no navigation aids (no mini-map, no pop-up map, no route line). The landmarks that were used as destinations for these tasks had all been seen previously in the training tasks (they were either used as destinations or were on a required route); however, since starting points were different for the test tasks, none of the routes had been used previously. After the four routes in each map, participants also completed the same experience questionnaire that was used during training. Participants completed test routes and questionnaire for the two maps in the same order as used for training.

At the end of the experiment, participants completed a debrief protocol and a final questionnaire, giving them an opportunity to provide comments about the experiment.

Study 1 Measures

At the start of the study, we collected measures of prior expertise and personality traits. During the study we collected information about navigation performance, spatial knowledge, and play experience.

Navigation Performance Measures

Route completion time. The system recorded each participant's total time to complete the eight training routes in each map, and the four test routes in each map. The maximum time per route was 90 seconds.

Map review time. The system recorded the total time that participants had the pop-up map open during training.

Distance travelled. The system recorded the total 3D Euclidean distance travelled by the participant for each route (using Unity's default measuring system).

Route Completion. The system recorded the number of routes where the participant reached the destination flag within the 90-second time limit.

Spatial Knowledge Measures

Scene-to-map translation: We presented participants with three screenshots for each environment, and asked them to indicate the location of that scene by clicking on one of six labels (A-F) on a 2D map. The scenes were ones that players had seen during training (although the screenshot was taken with a wider camera angle to show more of the scene).

Landmark-image-to-map translation: We presented participants with images of four landmarks from each environment, and asked them to indicate the location of the landmark by selecting one of six labels (A-F) on a 2D map. All of the landmarks had been seen during training.

Route duration estimate: For each map, participants were shown a 2D map with a route marked on it (not one they had traversed). Based on their experience with navigating the environment, they were asked to estimate the time it would take someone to navigate that path directly.

Confidence: After each spatial-knowledge question, we asked participants to rate their confidence in their answer.

Player Experience Measures

Task-Load Index (NASA-TLX) [22]**.** The NASA Task-Load Index questionnaire is a widely-used [35] questionnaire to rate perceived workload when completing a task. We used the questionnaire's mental demand, performance, effort, and frustration scales.

State Anxiety (SA) [36]. We anticipated that a participant's state anxiety could differ based on our conditions. We used Marteau and Bekker's six-item questionnaire of state anxiety to measure this construct.

Perceived Map Knowledge. To measure their perceived map knowledge after training, we asked users to rate their knowledge of the layout of the map.

Prior Expertise and Personality Traits

Several factors have been shown to affect a person's navigation performance in virtual environments, such as prior experience with virtual navigation, wayfinding anxiety, and immersive tendencies [50]. To account for these individual differences, we collected the following measures.

Experience with our chosen environments. Participants rated their experience with each of the two games (*Wolfenstein: Enemy Territory* and *Quake Live*) and each of the two maps (Gold Rush and Furious Heights).

3D gaming expertise. We asked participants questions to establish their gaming expertise: how much they self-identified as a gamer, their experience with video games, their experience with keyboard-and-mouse input in games, their FPS experience, and their experience with 3D games.

Immersive Tendencies. We used the Immersive Tendencies Questionnaire (ITQ) [53] to measure participants' tendency to experience presence in virtual environments. The questionnaire consists of three subscales: *involvement* (propensity to get involved with an activity), *focus* (ability to concentrate on enjoyable activities), and *games* (how much they play games and whether they become involved enough to feel like they are inside the game).

Wayfinding Traits. We measured each participant's trait anxiety and tendency to use a "route-learning" strategy or an "orientation" strategy using Lawton and Kallai's [32] International Wayfinding Anxiety Scale and International Wayfinding Strategy Scale, respectively.

Participants and Recruitment

The experiment was deployed on Amazon's Mechanical Turk (MTurk) crowdsourcing platform. MTurk connects willing workers to paid *Human Intelligence Tasks* (HITs) – it has been used for research purposes before and has been shown to be reliable [37]. We had 42 participants complete the experiment. Participants were paid \$6 USD for completing the experiment, which took 42 minutes on average.

We randomly assigned all participants to one of the three assistance levels, balancing for self-declared gender. We excluded 12 participants from our analysis for either rating themselves too high in prior experience (moderate experience or higher) with either of the two games or maps used, or for having too low a framerate on their system (<15 FPS). This left 15 female and 15 male participants (mean age 32.7, SD=7.56, min=20, max=53). Ten participants completed each of the three assistance conditions.

Data Analyses

For each participant, we aggregated performance data from both maps. This provided mean performance measures per participant for completion time, distance travelled, and routes completed (for each of training and testing). We also aggregated each participant's scores across both maps for the three types of spatial-knowledge question (scene location, landmark location, route duration estimation).

Due to our between-subjects design, we used covariates to acknowledge trait difference in anxiety and spatial ability in our participants. Covariates were chosen based on correlation between traits and dependent measures. For the subjective measures, four covariates were included: ITQ's focus subscale, ITQ's games subscale, wayfinding anxiety, and gaming expertise. For our objective measures, five covariates were included: ITQ's focus subscale, ITQ's games subscale, orientation wayfinding strategy, gaming expertise, and gender. Note that in both studies, one-way ANOVAs showed no significant group differences in the trait measures used as covariates, indicating that random assignment did not result in one of the assistance groups having skewed levels of any trait measure.

We expected differences between assistance groups during the training phase, and so performed two multivariate analyses of covariance (MANCOVA) using only the training data – one analysis for the subjective measures of experience (with four covariates), and one for the objective measures of performance (with five covariates). To test for effects of assistance level on performance and experience in the testing phase, we similarly carried out two MANCOVAs using the dependent measures collected during testing. Alpha was set at 0.05, and all pairwise comparisons used the estimated marginal means and Bonferroni corrections.

Study 1 Results

We first look at how assistance affected participant subjective experience and performance during training, and then report whether the type of assistance used in training affected performance or experience in the testing phase (where all navigation assistance was removed). Note that because there were different numbers of tasks in training and testing, and because the actual routes involved different start and end points, it is not possible to directly compare each group's training performance to their testing performance.

Effects of Assistance Level in Training

For the performance measures, there were significant main effects of assistance level on the time taken to complete the training routes, the time spent reviewing the map, the distance travelled, and the number of routes completed within the 90-second time limit (see Table 1). Pairwise comparisons showed that participants with moderate or strong assistance spent less time completing the training routes (p_m=.038, p_s<.001), travelled less distance (p_m<.001, p_s<.001), and completed more routes within the time limit (p_m=.044, p_s=.002) compared to participants with no assistance. Furthermore, participants with strong assistance spent less time reviewing the map than participants with moderate assistance (p=.050) or with no assistance (p=.005).

For the experiential measures, there were significant main effects of assistance on effort, frustration, perceived performance, and mental demand, but not anxiety or self-rated map knowledge (Table 1). Pairwise comparisons revealed that participants experienced higher effort (p=.013), frustration (p=.002), mental demand (p=.022), and perceived performance (p=.018) with no assistance compared to strong assistance. In addition, participants experienced higher frustration (p=.043) with no assistance compared to moderate assistance. No other pairwise differences were significant.

Effects of Assistance Level in Testing

For the performance measures, there were no effects of assistance type on any measure, including completion time, distance travelled, and number of routes completed. There were similarly no main effects of assistance type on the spatial-knowledge questions, including landmark location, scene location, and route duration estimation. In addition, there were no differences in participants' confidence ratings for landmark or scene location. For experiential measures, there were also no significant effects of assistance type on any measure, including effort, frustration, perceived performance, mental demand, and anxiety (See Table 1).

Summary of Results

In training, participants who had navigation assistance spent significantly less time completing the routes, spent less time looking at the map, and travelled a shorter distance. This reduced exposure to the 3D environment, however, did not translate into reduced performance in unassisted test tasks when compared to participants who had trained with no assistance (and whose testing experience was therefore much closer to their training experience).

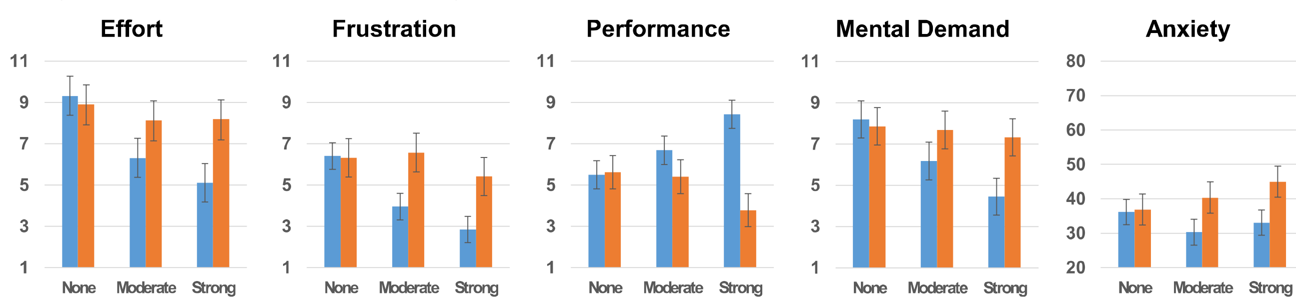

Figure 5. Experiential results after training (with assistance) and testing (with no assistance). Values are estimated marginal means, error bars are ±s.e.

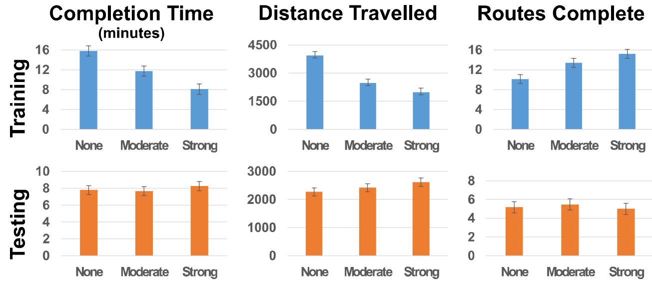

Figure 6. Descriptive statistic results for the performance measures of the 16 training routes and 8 testing routes. Values are estimated marginal means; error bars are ±s.e.

Navigation assistance also led to significantly better scores during training for perceived effort, frustration, performance, and mental demand. As with the performance measures, removing the assistance in testing did not lead to a worse experience than what was reported by participants who had trained with no assistance – we observed no differences in the subjective measures between the groups.

STUDY 2

Our first study suggested that navigation assistance helped participants during training, and did not hurt them (relative to the no-assistance group) when the aids were removed. However, the first study provided only a short training phase (eight routes in each map), and we wanted to determine whether differences might emerge if participants had more training time to learn the maps. Therefore, we conducted a follow-up study that used a much longer training period.

Study 2 Experimental Design

The second study was similar to the first but used three training sessions over three days. The study was again deployed on Amazon's Mechanical Turk, and we reproduced all aspects of the procedure described above. Participants completed the same navigation tasks for training and testing, with the same assistance levels used during training. We also used the same dependent measures.

The difference in Study 2 was the duration of training – three sessions on three consecutive days, totalling 48 navigation tasks instead of 16. The testing phase was identical to Study 1, and immediately followed the third training session.

Study 2 Participants and Recruitment

We recruited participants on MTurk using a qualification task, limited to 100 participants, in which people completed the tutorial navigation task and demographics questionnaire that we used at the start of Study 1. The qualification task took less than 5 minutes and paid $0.50 USD. The average framerate was logged during the navigation task. We excluded people from the main study if they had a framerate lower than 45 FPS (to ensure high framerates in the more graphically intense maps), or if they had moderate or greater experience with the two games and maps described above. After exclusions, 73 participants were eligible to participate in the main study.

The first day of the experiment was open to the first 50 participants who accepted the task on MTurk, and consisted of the personality trait questionnaires and a 16-route training session (as described earlier, 8 routes in each of two maps, seen in balanced order). Participants were paid $3.50 USD for completing the first day. The second day consisted only of the same 16-route training session, and participants were paid $3 USD. The final day consisted of the final 16-route training session, the same spatial-knowledge questionnaires as in Study 1, and the 8-route testing session, with the same testing routes as Study 1. Participants were paid $4.50 USD for day 3.

Of the 50 who started the multi-day study, 46 completed all three days. We excluded two participants from our analysis due to logging errors, leaving us with 44 participants (29 male, 15 female, mean age of 33.7, SD=8.68; min=20; max=59). Male and female participants were evenly distributed among the assistance groups as in Study 1. The 44 participants were randomly assigned to assistance levels: 14 had no assistance, 16 had moderate, and 14 had strong.

Study 2 Data Analyses

To evaluate the training sessions, we used a repeated measures MANCOVA – the same MANCOVA model as in Study 1 but with Day (one, two, and three) as an additional within-subjects factor. The testing session was analysed using the same statistical model as in Study 1.

Study 2 Results

Effects of Assistance Level and Day on Training

In terms of the performance measures, there were no main effects of day on the time taken to complete the training routes ($F_{2,72}$=0.73, p=.487), the time spent reviewing the map ($F_{2,72}$=0.67, p=.51), the distance travelled ($F_{2,72}$=0.72, p=.492), or the number of routes completed ($F_{2,72}$=1.6,

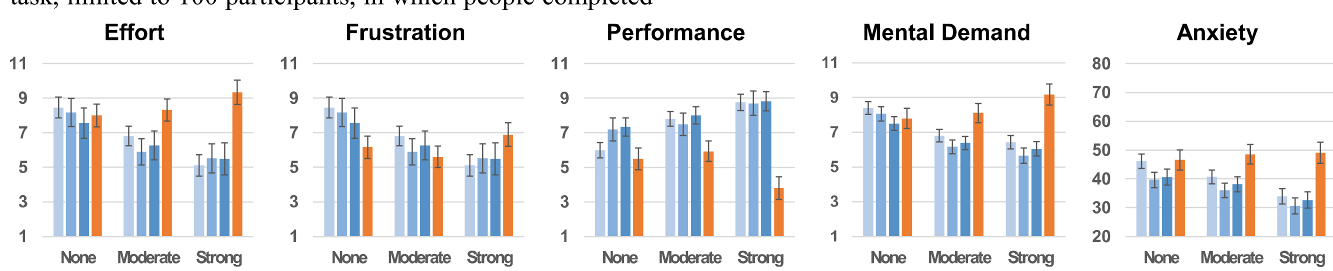

Figure 7. Descriptive statistics for subjective measures in Study 2 for day 1, 2, 3, and testing. Values are estimated marginal means; error bars are ±s.e.

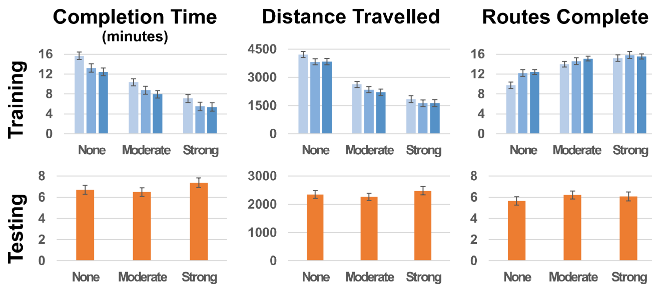

Figure 8. Descriptive statistic results for the performance measures of the 16 training routes and 8 testing routes for day 1, 2, 3, and testing. Values are estimated marginal means; error bars are ±s.e.

p=.218). There were significant main effects of assistance on the time taken to complete the training routes, the time spent reviewing the map, the distance travelled, and the number of routes completed (see Table 1). Pairwise comparisons showed that each level of assistance decreased the time spent (all p<.029) and the distance travelled (all p<.011). Furthermore, both moderate and strong assistance reduced the time spent on the map (all p<.020) and increased the number of routes completed (all p<.001). There were no significant interactions between day and assistance on time, time reviewing the map, or distance; however, a significant interaction between day and routes completed ($F_{4,72}$=3.7, p=.009, η_p^2=.169) showed that the differences between the assistance techniques were less pronounced over time.

In terms of the subjective results, there were no main effects of Day on effort ($F_{2,74}$=0.36, p=.696), frustration ($F_{2,74}$=0.36, p=.696), perceived performance ($F_{2,74}$=1.2, p=.299), mental demand ($F_{2,74}$=0.28, p=.759), anxiety ($F_{2,74}$=2.4, p=.095), or self-rated map knowledge ($F_{2,74}$=2.8, p=.066). There were significant effects of assistance level on effort, frustration, perceived performance, mental demand, and anxiety (see Table 1). Pairwise comparisons revealed that participants who trained with strong assistance experienced less effort (p=.040), frustration (p=.040), perceived performance (p=.021), mental demand (p<.001), and anxiety (p=.017) than those who received no assistance. In addition, those with moderate assistance rated their mental demand as lower than with no assistance (p=.001). There were no interactions between Day and Assistance on any of the measures.

Effects of Assistance Level on Testing

There were no significant main effects of assistance level on any of our performance measures, including time taken, distance travelled, and routes completed. There were also no main effects of assistance level on any of our spatial-knowledge questions, including landmark location, scene location, and route duration estimation. There were also no differences in confidence ratings (see Table 1). There were no significant effects of assistance on any of the subjective measures, including effort, frustration, perceived performance, mental demand, anxiety, or self-declared map knowledge (see Table 1).

		Study 1			***Study 2***		
		$F_{2,23}$	*p*	η_p^2	$F_{2,37}$	*p*	η_p^2
Effort	Train.	**5.31**	**.013**	**.316**	**3.61**	**.037**	**.163**
	Test	0.21	.812	n.s.	0.99	.381	n.s.
Frustration	Train.	**8.10**	**.002**	**.413**	**3.61**	**.037**	**.163**
	Test	0.43	.655	n.s.	0.89	.418	n.s.
Perceived Performance	Train.	**4.66**	**.020**	**.288**	**4.12**	**.024**	**.182**
	Test	1.53	.238	n.s.	2.95	.065	n.s.
Mental Demand	Train.	**4.33**	**.025**	**.274**	**12.0**	**<.00**	**.394**
	Test	0.09	.915	n.s.	1.37	.267	n.s.
Anxiety	Train.	0.60	.556	n.s.	**4.33**	**.020**	**.190**
	Test	0.80	.460	n.s.	0.14	.874	n.s.
Map	Train.	0.33	.725	n.s.	0.22	.800	n.s.
Time	Train.	**12.4**	**<.001**	**.529**	**26.6**	**<.00**	**.596**
	Test	0.33	.723	n.s.	1.02	.369	n.s.
Distance Travelled	Train.	**25.2**	**<.001**	**.696**	**57.2**	**<.00**	**.761**
	Test	1.34	.292	n.s.	0.57	.571	n.s.
Routes Completed	Train.	**8.29**	**.002**	**.430**	**16.5**	**<.00**	**.478**
	Test	0.16	.851	n.s.	0.57	.573	n.s.
Map Time	Train.	**6.64**	**.006**	**.376**	**12.9**	**<.00**	**.418**
Landmark ID	Test	0.21	.815	n.s.	0.22	.801	n.s.
LM Conf.	Test	0.42	.662	n.s.	0.04	.959	n.s.
Scene ID	Test	0.54	.591	n.s.	1.99	.152	n.s.
Scene Conf.	Test	0.13	.883	n.s.	0.17	.841	n.s.
Route Est.	Test	0.32	.730	n.s.	0.48	.241	n.s.

Table 1. MANCOVA results for the effects of assistance on the subjective and objective measures for the training session and testing session.

Summary of Results

The findings from Study 2 mirror the findings from Study 1, with the additional result that anxiety during training was higher without assistance. As Figures 7 and 8 show, the longer training period did not substantially change any of our subjective or performance measures.

DISCUSSION

Summary of Results

Our expectation, based on the guidance and retrieval-effort hypotheses, was that increased navigation effort in training would result in better spatial understanding of the map, and thus better performance during testing. However, this did not occur in either study. Although it was clear that both kinds of navigation assistance helped when they were present, we found no differences in route-finding performance when assists were removed, and no difference in spatial-knowledge questions (regardless of the duration of the training period – 16 or 48 routes). The lack of differences across assistance level is even more surprising given that the overall time in the game world for the no-assistance group was approximately double that of the strong assistance group, and 1.5 times that of the moderate group. In addition, navigation assistance improved subjective experience. When assistance was taken away during the testing session, the differences between assistance groups disappeared.

Possible Explanations for Results

There are several possible reasons why navigation assistance did not hinder route-finding performance once the assists were removed. First, it may be that incidental learning took place during training (as suggested by previous work [2,23]), even though the navigation tasks were made easier by the assistance. One mechanism for this incidental learning could be that the assistance reduced the cognitive effort of the task to the point where players could pay more attention to their surroundings. We believe it is important that players still experienced the entire route and participated in traversing it, even though they were assisted – if the assist had taken the player out of the route (e.g., by teleporting them to the destination), the opportunity for incidental learning would have been much reduced.

A second (and related) possibility is that spatial learning was somehow hindered by the no-assistance condition. It is possible, for example, that the tasks were so difficult for novices that they were outside Vygotsky's "zone of proximal development" where people learn best [49] (similar to the "flow state" in Kiili's learning model [29]). Players in the no-assist condition may have been unable to learn the maps effectively because they were overwhelmed by the basic actions of locating themselves on the map, recognizing landmarks, and understanding the relationships between the pop-up map and the first-person view of the game world.

Implications for Game Designers

The use of assistance did not have a significantly negative effect on performance in the test tasks – even despite the large differences in training time. This finding has intriguing consequences for utilizing route guidance as an assistance technique in games.

Skill Development Considerations

Some games are better candidates for navigational assistance than others. There are many games that require players to operate in the same environment many times, so players must become familiar with the maps if they want to succeed.

Skill assists have been investigated previously to improve player balancing [7,48], but a common concern is that providing assistance will result in player reliance. Our results add to increasing evidence that some degree of assistance does not necessarily reduce learning. For example, Gutwin et al. [20] found that providing aim assistance to novices did not hinder the development of either aiming skill or overall FPS abilities. When games require many skills, providing assistance in one area (and thus reducing effort overall) can allow players to improve in other areas. For example, navigation assistance in an FPS game could free the player to work on skills such as aiming, movement, or monitoring audiovisual cues [27].

It is even possible that providing dynamic skill assistance can enhance learning. Kiili's [29] experiential gaming model proposes that a balanced game that facilitates the player reaching a flow state will result in the strongest learning. This corresponds to Anderson and Bischof's suggestion that guidance gradually be removed as a learner gains expertise [1]. Gradual removal of the assist would also reduce the sharp drop in experience measures that we observed between training and testing.

There are still likely to be cases in which providing a strong assist for a particular skill results in a dependency on the assist. Further research is required to determine when and where this effect appears.

Implementation Considerations

We chose our assistance techniques because they are already used extensively in games. The augmented (moderate-assistance) map works if the player has time to study it, and the glowing trail works if the destination is known to the system. The trail allowed participants to reach a higher level of performance in less time than the augmented map, so it may be worthwhile to consider implementing it in more games. In games where destinations are not known (or where there are many possible destinations), it is not clear how well this method will work.

Assistance could be made context-sensitive: for example, if a player has no weapons or is low on health, the game could show a trail to the nearest weapon or the nearest health pack. A player's role in a team game could also determine which routes are visualized for that player (e.g., a trail to a wounded player for a medic role). Finally, for scenarios in which navigational assistance is not possible, or where the player chooses to turn off the aids [12,38], it appears that the use of even strong assistance early in a player's experience will not significantly affect their long-term performance.

CONCLUSIONS AND FUTURE WORK

3D game navigation is difficult for novices. Games can provide visual assistance for wayfinding, but there is a risk that players will become overly reliant on these assists and fail to develop independent spatial understanding. We investigated the benefits and potential risks of navigation assistance through two online studies. We found that having assistance helped significantly when it was turned on – and when it was turned off, navigation performance did *not* suffer. This work provides new evidence that navigation assistance is a valuable tool to help novices deal with the complexities of 3D games, and that incidental learning of 3D game environments can occur, even with strong assistance.

In our future work, we plan to examine several issues raised by our experiments. First, we will look in more detail at whether navigation assistance acts as a scaffold that can improve learning (by putting players in a flow zone or zone of proximal development). Second, we will test other kinds of navigation assistance and other game environments to see if our results hold in different settings. Third, we will develop versions of the assist that gradually disappear, to see if this further improves spatial knowledge. Fourth, we will test our techniques in actual play settings, to see if navigation assistance can improve play experience and player balancing in real games.

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