Investigating route learning, metacognition, and beacon-based strategies using virtual environments

NB: Previous title was “Using virtual environments to investigate wayfinding in adults”

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**Abstract**

Introduction

Dominant theories of wayfinding may have underestimated the ease with which adults can learn a route, even with minimal exposure to that route.

Objectives

In this paper we present three different experiments to provide a comprehensive picture of whether adults can learn complex routes consisting of a number of choicepoints, and if so, what strategies they might be employing to do so.

Method and results

We found that adults could learn a 15-junction route after only a single experience of the route (Experiment 1) but that they underestimated how good they would be at learning the 15-junction route (Experiment 2). In Experiment 3, we found that when learning a route made up of ‘T’ shaped junctions, participants relied on a *‘beacon’* strategy based on visual matching.

Conclusions

Collectively, these findings suggest that adults can learn complex routes, even with as many as 15 choicepoints, very quickly and without the need for repeated exposure. These findings have implications for theories of wayfinding and call into question the need for repeated exposure.

**Keywords**

wayfinding; virtual environments; landmarks; route-learning; strategies; visual matching

Une évaluation des capacités de navigation spatiale chez l’adulte à l’aide d’environnements virtuels

**Abstract**

Introduction

Les théories de la navigation spatiale pourraient avoir sous estimé la facilité avec laquelle les adultes peuvent apprendre un itinéraire, même à partir d’une exposition minimale à celui-ci.

Objectifs

Trois expériences ont été réalisées pour montrer que l’adulte peut apprendre rapidement un itinéraire composé de nombreux changements de direction et pour identifier la stratégie utilisée dans ce cas.

Méthode et résultats

Les participants ont appris un itinéraire composé de 15 changements de direction après une seule exposition à celui-ci (expérience 1). Ils sous estimaient cependant leur performance lorsqu’on leur demandait de prédire le nombre d’essais nécessaire à l’apprentissage (expérience 2). Dans l’expérience 3, les participants ont appris un itinéraire composé d’intersections en « T ». Leur comportement d’exploration visuelle suggérait l’utilisation d’une stratégie d’une stratégie de suivi de balise qui est basée sur la reconnaissance visuelle.

Conclusion

Dans l’ensemble, nos résultats suggèrent que l’adulte peut apprendre rapidement un itinéraire complexe constitué de 15 intersections. Ils ont des implications pour les théories de la navigation spatiale et remettent en question la nécessité d’avoir une expérience répétée d’un itinéraire pour l’apprendre.

**Mots clés**

Navigation spatiale; Apprentissage d’itinéraire; Environnements virtuels

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**Introduction**

Researchers have long been interested in our ability to learn and recall a route through an environment; a skill commonly referred to as wayfinding or route learning. Adults are particularly good at learning routes and can learn routes, even after only experiencing them once (Gärling, Böök, Lindberg & Nilsson, 1981; Montello, 1998). This is the case even when the routes include numerous choicepoints[[1]](#footnote-1) (Farran, Blades, Boucher, & Tranter, 2010; Karimpur & Hamburger, 2016; Lingwood, Farran, Courbois, Blades, & Matthews, 2018). Therefore, most adults can find their way to various places in their everyday lives, yet little is known about how adults initially learn these routes (Kitchin & Blades, 2002; Waller & Lippa, 2007).

It is not clear why adults are so proficient at wayfinding. Previous studies of adults’ wayfinding capabilities have often underreported the methodological details of those studies. For example, details concerning number of turns or choicepoints used, number and types of landmarks, and number of intersections are commonly unreported (e.g., Baldwin & Reegan, 2009; Galea & Kimura, 1993; Head & Isom, 2010; Heft, 1979; Heth et al., 2002; Jansen et al., 2010; Kato & Takeuchi, 2003; Meneghetti et al., 2012). Therefore, the impact of these factors on how adults learn routes is currently unknown (Golledge, 1987; Jansen-Osmann, 2007). Additionally, some studies have focused on wayfinding in environments that participants were already familiar with (e.g. Cornell et al., 2001; Cousins et al., 1983) and so participants may have already known the routes they were being asked to retrace. Other studies have asked adults to explore an environment rather than learn a particular route (see Jansen-Osmann, 2002; Jansen-Osmann & Wiedenbauer, 2004). Although these studies have their place in the wider literature, they are not informative about route learning per se.

For the reasons above, we still do not fully know how adults learn routes so effectively. It has been assumed that adults have a good understanding of their own spatial capabilities (Mark & Frank, 1990). In fact, little is also known about how people monitor their own spatial knowledge and judgments (Stevens & Carlson, 2016). This metacognitive knowledge is an important component of learning, and it can encourage us to adopt or abandon particular strategies when performing tasks (Sternberg, 1997). Those that have investigated spatial metacognition using global measures (Liberman, 2004) have relied on asking participants to rate their *overall* abilities, confidence, or comfort during a spatial task (e.g., Kato & Takeuchi, 2003; Kozlowski & Bryant, 1977). Only by using more fine-grained measures, can we assess whether adults would be accurate in estimated their own ability to learn a *specific* route (Lemieux, Collin & Watier, 2019).

Our knowledge of adults’ wayfinding abilities is further limited when we turn to dominant theories of route learning. Previous theories of wayfinding do not adequately explain how adults can learn complex routes, with minimum exposure to them. Stage theories of wayfinding proposed that adults learn routes gradually over time in a systematic manner, first learning individual landmarks along a route before associating those landmarks with particular decisions (e.g., left or right turns) and finally combining landmarks and turns into a learned route (Hart & Moore, 1973; Siegel & White, 1975). Alternative frameworks (e.g. Montello, 1998; Ishikawa & Montello, 2006) adopt a more ‘individual differences’ approach and suggest that landmark, route and survey knowledge can develop at any time, and in any order. For example, Ishikawa and Montello (2006) tested 24 students’ environmental knowledge of two unfamiliar routes over a 10-week period. At various time points, participants were given a series of distance and direction estimation tasks, map sketching tasks and a sense of direction questionnaires. A collection of these measures showed that spatial knowledge was not attained in a stage-like manner as suggested by stage theories of wayfinding. Rather, landmark, route and survey knowledge were acquired at different times and rates across participants.

Regardless of how these frameworks describe adults’ ability to gain knowledge of an environment, it is evident that neither framework discusses *how* this knowledge comes about. For example, there is no discussion of strategies that adults may use to learn routes nor is there any discussion about how environmental features other than landmarks might affect route learning. Given that adults can learn routes so effectively, this suggests they may have developed strategies for learning routes (Montello, 2017), which will be discussed below.

Landmarks are considered to be important for successful performance on wayfinding tasks as supported by both behavioural data (Jansen-Osmann, 2002; Karimpur & Hamburger, 2016) and brain imaging data (Wegman & Janzen, 2011). For example, adults show increased brain activity in the parahippocampal gyrus when attending to landmarks at critical choicepoints (Janzen, Wagensveld, & van Turennout, 2007) and are quicker to respond to landmarks which appear only once (unique landmarks) than landmarks that occur more than once (non-unique landmarks; Wiener, De Condappa, & Hölscher, 2011). Furthermore, landmarks placed at critical choicepoints are more likely to be remembered than those at non-critical choicepoints (Aginsky et al., 1997; Farran, Courbois, van Herwegen, & Blades, 2012; Janzen, 2006).

Landmarks are also crucial for determining one’s position along a route, or for determining which direction to move in at a particular decision point (Wang et al. 2014). The two most commonly discussed strategies in the literature are an egocentric strategy, and an associative strategy (O’Keefe & Nadel, 1978; Tolman, 1948). Using an egocentric strategy, one learns a route as a series of turns (e.g., turn left, then left again and then turn right). The sequence must be followed in the exact manner however, to avoid an accumulation of errors (Bruyné et al., 2017). A more flexible alternative would be an associative based strategy whereby the individual learns an association between a landmark and a turn (e.g., turn left at the corner shop). However, like an egocentric strategy, an associative strategy also requires explicit coding of directions. Therefore, using either strategy with numerous turns or choicepoints would be cognitively taxing (Golledge, 1987; Hayashi, Fujii, & Inui, 1990; Lingwood et al., 2018; Sameer & Bhushan, 2017). Indeed, there is evidence to suggest that associative strategies are only used after multiple exposures to a route (de Condappa & Wiener, 2016; Wang et al., 2014).

A third alternative strategy is to scan the scene for, and walk towards, a known landmark (a ‘beacon’). By adopting this strategy, the traveller must recognize which landmarks do and do not lead to a goal. Unlike route learning based on associative cues, a beacon-based strategy is not based on learning directional information (Waller & Lippa, 2007). In a series of experiments, Waller and Lippa (2007) asked participants to use either an associative landmark or a beacon landmark. In the associative cue condition one landmark was located between two doors. In the beacon condition two different landmarks were placed adjacent to each door. Participants who were required to use landmarks as beacons made fewer errors than participants who used landmarks as associative cues across both between and within participants designs. Furthermore, these experiments showed that landmarks that served as beacons were better remembered by participants than landmarks that served as associative cues. Beacon-based strategies can therefore be seen as superior to associative strategies in certain environments (Wiener et al., 2013), challenging the dominant view that landmarks serve solely as associative cues to route learning (O’Keefe & Nadel, 1978; Siegel & White, 1975).

One beacon-based strategy is ‘visual matching’ (e.g. Broadbent et al., 2014) or sometimes referred to as ‘place recognition’ (Cornell et al., 1994). Using a ‘visual matching’ strategy, the traveller looks down each path and decides to approach the landmark if they recognise it as being on the correct route (Wang et al., 2014). This strategy has also been discussed by Cornell et al. (1994) who more broadly argued that an individual can retrace a route by walking down paths that contain any features (such as landmarks) that are familiar to them. A traveller can use a ‘visual matching’ / ‘place recognition’ strategy to decide if they recognise the visual array as being part of the route. According to Wang et al. this ‘visual matching’ strategy is the most effective in an unfamiliar environment and crucially participants are not reliant on explicit memories of the turns or choicepoints of the environment (see also Cornell et al., 1994).

‘Visual matching’ may also be an effective strategy, particularly for atypical populations. Purser et al. (2015) suggest that when learning a route in a VE, Williams Syndrome (WS) participants adopted a ‘visual matching’ strategy and looked down junctions first before deciding which way to go. Indeed, WS participants outperformed a non-verbal matched subset of typically developing (TD) children on more complex routes. ‘Visual matching’ may not be an optimal strategy in some environments, however, and Broadbent et al. (2014) argued that a view-matching strategy is time-consuming and inefficient when needing to understand the configuration of the environment or when landmarks are non-unique.

In this paper we present three experiments with the aim of providing a comprehensive picture of whether adults can learn complex routes consisting of multiple turns or choicepoints, and if so, what strategies they might be employing to do so. To createand manipulate a diverse range of environments (Jansen-Osmann & Wiedenbauer, 2004; Lingwood et al., 2015b), we used virtual environments (VEs) in the current study.VEs depict visual and spatial information from a three-dimensional first-person perspective (Jansen-Osmann, 2002), and successful route learning in VEs has been shown to transfer to real environments (Ruddle, Payne, & Jones, 1997). VEs are a valid alternative to real and simulated environments (Bullens et al., 2010a) and have been shown to tap into the same cognitive processes (Richardson et al., 1999).

In Experiment 1 we assessed the ability of adults to retrace a route with 15 decision points in a VE. Participants were shown the route from start to finish, once, and then were asked to retrace the route, from the start. We were interested in whether the participants could successfully retrace the route after a single experience. Golledge (1992) reported, with reference to Miller’s (1956) working memory capacity study, that a nine-turn route is the “upper asymptote of route segments that can be learnt with relative efficiency and low error” (p. 208). This suggests that people should have difficulty recalling a long route without errors and implies that people will need to make an effort to encode long routes. However, more recently, Lingwood et al. (2018) showed that even after a single experience of a route, three-quarters of the adult participants in their sample could successfully retrace a 12-choicepoint route in a VE, without making any errors. The second aim of Experiment 1 was therefore to replicate Lingwood et al. (2018) using the same method. Therefore, for Experiment 1, our research question was whether adults could retrace the route after a single experience of it, and if so, how many errors would they make in the process. Based on the findings from Lingwood et al., it was predicted that adults would be able to successfully retrace the 15-choicepoint maze in Experiment 1, without making many errors.

In Experiment 2 we showed a different group of adults the same 15-choicepoint maze from Experiment 1 and asked them how many mistakes they estimated they would make and how many trials they would require to learn the route if they were to retrace the route themselves. Our research question was to find out about their metacognitive abilities, specifically whether typical wayfinding performance (from Experiment 1) and expectations (from Experiment 2) were aligned with one another. To our knowledge, wayfinding expectations had not been investigated in this way before. In Experiment 3, our research question was to explore the strategies participants may be using to retrace novel routes.

**Experiment 1**

**Methodology**

*Participants*

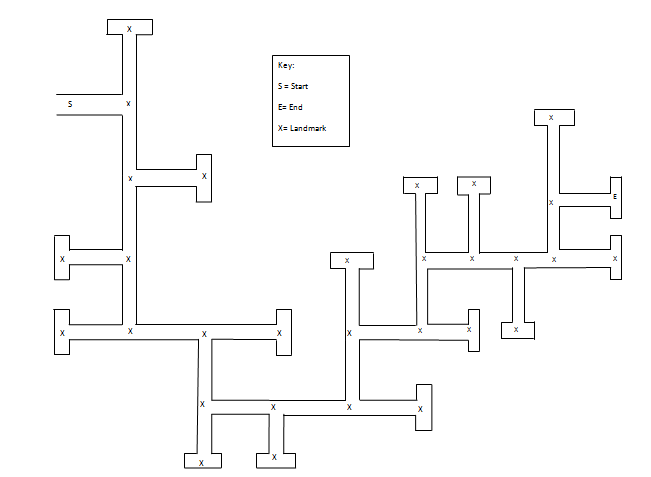
Twenty adults, mainly postgraduate Psychology students (*M* = 26;5, SD = 3;9, range = 22;7 to 37;8) were sampled at the University of Anonymised. Half were male and half were female. Ethical approval was granted by the University of Anonymised Department of Psychology ethics committee.

*Apparatus and materials*

VE mazes were created using Vizard Development Edition software (www.worldviz.com). VEs were presented to adults on a 17-inch laptop and participants walked through the maze using the keyboard arrow keys. Walking speed was consistent across all participants.

A practice maze was used to familiarise the adults with walking in a VE. This maze was a similar layout to the test maze but it did not contain any landmarks.

There was one brick wall test maze with 15 junctions (see Figure 1). Each junction had two possible directions and the 15 junctions included five right, five left, and five straight ahead correct choices. Maze designs were based on previous mazes used in other published papers (see Lingwood et al., 2015a; 2015b, 2018).



*Figure 1: 15-choicepoint two choice point maze used in Experiment 1 with each X depicting a different landmark*

The brick wall test maze contained 30 landmarks. The landmarks were chosen from a variety of categories: toys (ball, slide, robot, dice); vehicles (bus, car, bike, helicopter); furniture (bench); animals (cow, horse, bird, chicken); vegetation (tree, pineapple, apple, plant, pineapple, berries); road-side objects (traffic, street lamp); and other (teapot, clock, hat, candle, sunglasses, ring, crown, lightbulb, torch, trumpet, wheelbarrow). Landmarks (15 of each) were placed at path junctions and dead-end junctions.

*Procedure*

The adults were tested individually and completed the experiment in a quiet room in the Psychology department at the University of Anonymised. Informed consent was obtained prior to data collection.

The experimenter introduced the task by saying, ‘This computer has got some mazes on it that we are going to use. First, we’re going to practice using the computer to walk around a maze. I’ll go first and show you how, and then you can have a turn.’ The experimenter then showed the participant how to use the arrow keys on the keyboard to effectively move through the maze. Participants were then allowed to freely explore the practice maze. The goal was to ascertain that they were confident in using the arrow keys to navigate, rather than to learn a route. The experimenter then ended this practice phase by saying, ‘Well done, I think you’ve had enough practice now, do you? Let’s have a go at another maze now.’

All participants were told the same instructions for the test phase: ‘Now I’m going to show you the way through a new maze. Somewhere in this maze there is a little grey duck to find. I’ll show you the way to the grey duck once, and then you can have a go.’ The experimenter then demonstrated the correct route from the start to the end of the maze and used generic terms such as ‘You go past here, then you turn this way, and then you turn this way’. The experimenter did not use any directional language, such as ‘Turn right’. At the end of the demonstration, the experimenter exclaimed, ‘We’ve found the duck!’, and the screen went blank.

The participant was then asked to retrace the route they had been shown from the beginning of the maze and to use the arrow keys to walk through the maze. The experimenter sat adjacent to the participant and marked the route the participant took on a hard copy of the maze, out of the participant’s sight.

When the participant reached the end of the maze, they were then asked to retrace the route again from the beginning. This procedure was repeated until the participant had walked the route to a criterion of two consecutive completions without error.

**Results**

To successfully learn the route, participants were required to demonstrate two consecutive completions of the route without error. Participants had to achieve this without walking down any incorrect paths on two consecutive learning trials. Walking down an incorrect path beyond half-way was classed as an error, whereas looking down an incorrect path was not classed as an error. The final two trials whereby participants made no mistakes were excluded from the total number of learning trials to reach criterion. For example, if a participant made an error on trial 1, but then walked the route without error on trials 2 and 3, they would be scored as having required 1 trial to reach criterion. A lower score indicated better performance.

Participants received a mark of 1 for every error they made during a trial. On each trial a proportional error score was calculated as the number of errors divided by the number of decisions made. For example, if a participant made 5 errors out of a total of 13 decisions, this they would receive a proportional error score of 0.38. This scoring captured participants’ wayfinding behaviour every time a decision at an intersection was made. This scoring method also accounted for occasions when participants doubled back and returned to the same junction more than once within a trial. On the rare occasion that participants did not reach a junction, for example, if they got lost, these junctions not reached were also scored as errors. A mean proportional error score was calculated for each participant across learning trials.

Therefore, this proportional error score captured all of a participant’s behaviour on all trials. Therefore, we report only the proportional error scores. This scoring system was based on other previous papers (see Lingwood et al., 2015a; 2015b, 2018)

To answer our research question, we examined whether participants could learn the route, and if so, how many errors they made in the process. All participants were able to successfully reach the learning criterion. Participants made very few errors when learning the maze (*M* = 0.25, SD = 0.79). As a proportional error score this was very low (*M* = 0.01, SD = 0.02). Participants required very few trials to reach the learning criterion (*M* = 0.15, SD = 0.49).

Participants were very good at retracing the route, making almost no errors. The probability of being able to complete the route accurately by chance was 0.00003051757/1 (0.515) yet 18 out of 20 participants were able to learn the maze without making a single error.

**Discussion**

Experiment 1 demonstrated that adults could learn and remember a 15-choicepoint route in a VE, having viewed the route just once and participants did so without making many errors and without requiring many additional trials to reach learning criterion. To successfully learn the route, the adults had to learn and remember 15 different choicepoint decisions and yet most participants (90%) made no errors at all when retracing the route. This replicates the findings from Lingwood et al. (2018) who previously showed that adults (*N* = 20) also made very few errors when walking through a 12-choicepoint maze. In Lingwood et al. (2018) most participants (75%) also made no errors at all when retracing the route. Combined, these two studies show that adults are capable of learning routes with more than nine choicepoints without making many mistakes at all. These two studies also show that most adults can learn a route immediately having seen it only once. According to Wang et al. (2014) adults are capable of learning landmark knowledge for guidance (beacon-based route knowledge) but are not able to use an associative strategy after just one experience of a route. This suggests that the very good performance of adults in Experiment 1 could be explained by a beacon-based ‘visual matching’ strategy. This is something we will explore further in Experiment 3.

Stage theories of wayfinding (e.g., Siegel & White, 1975) would not have predicted this pattern of findings because in Experiment 1 adults did not learn the route as a series of qualitative changes in their wayfinding strategy (from landmark to route knowledge), nor did they require repeated exposure of the route. Rather, for most adults’ ‘route’ knowledge was obtained immediately, suggesting that adults can learn routes in a more continuous manner (Montello, 1998). The findings from Experiment 1 also contradict Montello’s (1998) framework of how adults learn routes. Montello argued that adults can acquire landmark, route and survey knowledge at any time, but that this knowledge improves with increased exposure to a route. For example, Ishikawa and Montello (2006) found that there were large individual differences in the rate at which adults learnt two overlapping routes across a period of 10 weeks. Although some acquired ‘survey’ knowledge almost immediately, others were not able to demonstrate evidence of ‘route’ knowledge after 10 weeks. However, our data from Experiment 1 (and Lingwood et al., 2018) showed that adults did not require much exposure to develop ‘route’ knowledge. There are a number of differences in task design between the current study and Ishikawa and Montello. In the Ishikawa and Montello study, they used a real environment in an area “full of hills and winding roads…there are few distant landmarks that may be used consistently as orientation clues. Its road signs are small, inconspicuous, and few in number. Hence, accurate orientation on the first visit to the area, if not after several visits, is quite challenging” (p. 100).

Given how well adults learnt the 15-choicepoint maze in Experiment 1 we were interested in how adults estimated their own metacognitive route learning abilities for this maze. Previous researchers who have investigated route learning estimations have focused on asking participants to estimate distances (Cousins et al., 1983; Matthews, 1981; Jansen-Osmann & Berendt, 2002, 2005) or asking participants to point to landmarks (Cornell et al., 2001; Cousins et al., 1983; Golledge et al., 1992; Hund & Nazarczuk, 2009). Some researchers have used sense of direction (SOD) scales to explore how participants rated their own wayfinding abilities (e.g., Kato & Takeuchi, 2003; Kozlowski & Bryant, 1977), whilst others have classified participants with good or poor SOD depending on how they performed on route learning tasks (e.g., Baldwin & Reagan, 2009; Ishikawa, 2013; Nori et al., 2009). However, less research has been conducted on metacognition with respect to route learning.

In Experiment 2 we showed the 15-choicepoint maze from Experiment 1 and asked them how many mistakes they estimated they would make and how many trials they would require to learn the route if they were to walk the maze themselves. We wanted to find out whether route learning estimations would correlate with actual route learning performance (based on the performance from a different group of adults who participated in Experiment 1).

In Experiment 2 the VE was presented on a large 84-inch screen to several participants at once. All participants therefore made route learning estimations based on the same route, immediately after experiencing it. This contrasts with previous studies that have relied on participants to give SOD assessments based on long-term recall (Kato & Takeuchi, 2003; Kozlowski & Bryant, 1977; Heth et al., 2002), which Heth et al. (2002) argued may bias results.

For Experiment 2 we explored route learning estimations in relation to similar measures used in Experiment 1: number of errors made and number of trials to reach learning criterion. We also investigated whether sex and experience with maps or computers influenced estimations of route learning. Although there is no evidence that any sex differences exist between men and women in relation to actual route learning performance (Coluccia & Louse, 2004; Lawton, 2010), women have been shown to be less confident in their route learning abilities in comparison with men[[2]](#footnote-2) (Lawton, 2010). Furthermore, wayfinding performance correlates with other variables such as previous experience related to wayfinding (Malinoswki & Gillespie, 2001; Newcombe et al., 1983). Thus, while we purposely selected a sample of students who were not geographers, cartographers or orienteers we investigated whether map or computer experience affected participants’ estimations too.

Given the lack of research on how people monitor their spatial knowledge and judgments during route learning tasks, we did not have a directional hypothesis concerning whether or not performance (from Experiment 1) would relate to estimated performance (from Experiment 2). Similarly, it was unclear from previous research whether map or computer experience would necessarily correlate with wayfinding judgements. However, based on the literature (see Coluccia & Louse, 2004; Lawton, 1994, 2010; Lawton & Kallai, 2002), we did expect women to be less confident in their route learning abilities in comparison with men.

**Experiment 2**

**Methodology**

*Participants*

There were 72 adults (51 males, 21 females) with a mean age of 18 years 10 months, SD = 0.5 (range 18 years 3 months and 20 years 1 month) who were undergraduate students at University of Anonymised. Most of these students studied modern languages and as far as we were aware, none of these students were geographers, cartographers or orienteers. Ethical approval was granted by the University of Anonymised Department of Psychology ethics committee.

*Design and procedure*

The 15-choicepoint test maze from Experiment 1 was used (see Figure 1).

Adults filled out a route learning questionnaire. These questions concerned age, sex, map experience, computer experience, as well as route learning estimations regarding (i) number of mistakes participants would make if they were to retrace the route, and (ii) number of individual trials participants would need to learn the route without making any mistakes.

Experiment 2 was conducted in the Psychology lecture theatre. The experimenter said: “I am from the Psychology department and would like to conduct a short study with you. You do not have to take part if you do not wish to. I am going to walk you through a computer maze on the big screen. The maze has 15 choicepoints. After the maze has finished I want you to turn over the piece of paper in front of you and fill out the short questionnaire without conferring with anybody around you”.

The experimenter then ‘walked’ through the 15 choicepoint route on the lecture theatre screen, this took around 60 seconds to walk from start to finish. Participants then filled out the route learning questionnaire.

**Results**

To answer our research question, we firstly investigated route learning estimations using the same dependent variables as used in Experiment 1, and how they relate with route learning performance from Experiment 1.

Participants’ estimations of the number of errors they would make ranged from 0 to 23 (*M* = 5.56, SD = 3.25). As shown in the Figure 2, the mode was 5 errors. This estimate was given by 23.6% of participants.

*Figure 2: Estimated number of errors participants predicted they would make when retracing the route.*

Frequency of errors

Estimated number of errors

Participants estimated that they would require several trials to learn the maze (*M* = 5.13, SD = 3.24), ranging from 1 to 20. As shown in Figure 3, the mode was 3 trials. This was given by 26.4% of participants.

*Figure 3: Estimated number of trials required to reach learning criterion.*

Frequency of required learning trials

Estimated number of trials

There was a positive correlation between estimated number of errors and estimated number of trials (r = 0.33, *n* = 72, *p* < .01).

We compared estimations with the route learning data from Experiment 1 where actual route learning performance was very good and participants made very few errors (*M* = 0.25, SD = 0.79) and required very few trials to reach learning criterion (*M* = 0.15, SD = 0.49). In Experiment 2, adults predicted they would make several errors (*M* = 5.56, SD = 3.25) and require several additional trials to learn the maze (*M* = 5.13, SD = 3.24). Independent samples t-tests showed that there were significant differences between route learning performance (Experiment 1) and route learning estimations (Experiment 2) for number of trials to reach criterion (t (79.88) = -12.46, , *p* < .001, 95% CI [-5.80, -4.20], d = 2.15), and for number of errors made (t (86.94) = -12.46, *p* <.001, 95% CI [-6.15, -4.46], d = 2.25).

We then investigated whether sex and experience with maps or computers influenced estimations of route learning. There were no sex differences for estimated number of mistakes between males (*M* = 6.38, SD = 4.58) and females (*M* = 5.20, SD = 2.45) (t = 1.40, df = 68, *p* = 0.17). Similarly, there were no sex differences for estimated number of trials to reach learning criterion between males (*M* = 5.38, SD = 3.28) and females (*M* = 5.02, SD = 3.25) (t = 0.43, df = 69, *p* = 0.67).

There was no correlation between estimated number of mistakes and participants’ self-reported experience with computers (r = -0.11, *n* = 72, *p* = 0.36), or maps (r = -0.15, *n* = 72, *p* = 0.22) and no correlation between estimated number of trials to reach learning criterion and participants’ experience with computers (r = -0.04, *n* = 72, *p* = 0.76), or maps (r = -0.20, *n* = 72, *p* = 0.10).

**Discussion**

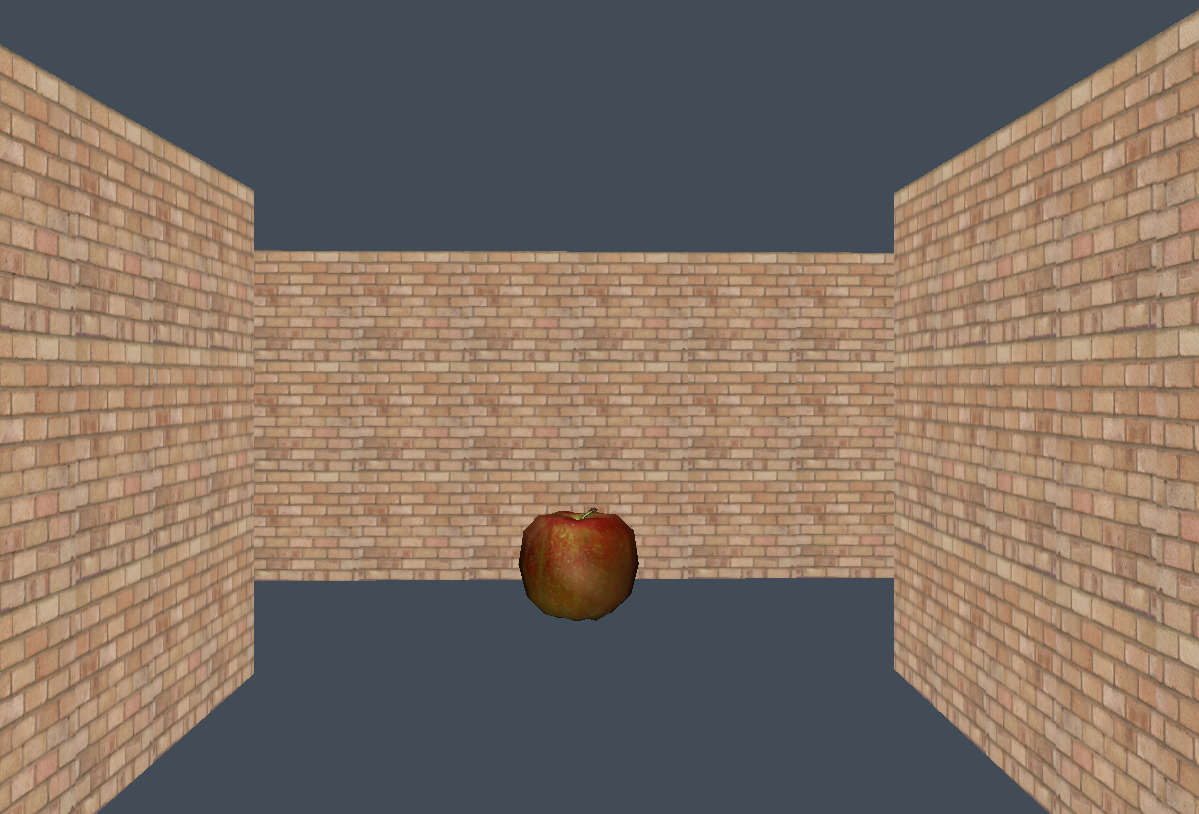
Experiment 2 showed that participants severely underestimated how good they would be at learning and remembering a 15-choicepoint route in a VE, estimating that they would make several mistakes and require a number of trials in order to successfully learn and remember the route. This differs considerably from the findings from Experiment 1 which showed that participants made very few errors and required very few trials to reach learning criterion. This is consistent with a previous study in which self-ratings of SOD prior to performing a route learning task also did not correlate with route learning performance (Heth et al., 2002). However, we acknowledge that different participants took part in Experiment 1 and 2. Although we have no reason to believe that the participants in each experiment had notably different characteristics from one another that would aid or hinder route learning performance or expectations, we cannot rule this out.

In Experiment 2 we found no evidence of any differences between males and females in relation to their route learning estimations which contradicts some of the literature on this (see Coluccia & Louse, 2004; Lawton, 1994, 2010; Lawton & Kallai, 2002). However, in Experiment 2, less than one third of participants were male and so the sex ratio was skewed in favour of females. We also found no evidence to suggest that experience with maps or experience with computers affected route learning estimations. Whilst computer experience is not normally correlated with route learning (Jansen-Osmann, 2002), experience with maps has been shown to be correlated with successful wayfinding performance (Malinowski & Gillespie, 2001). However, in our questionnaire these were yes/no self-reported measures which may have been unlikely to have affected estimations due to their subjectivity. Additionally, we purposefully chose a selection of students who as far as we were aware were not geographers or orienteers. Therefore, we were not surprised to find that neither map nor computer experience influenced estimations.

How do we account for these differences between wayfinding performance and expectations? Unlike Experiment 1, in Experiment 2 adults were not walking the route themselves. On account of the passive nature of their experience of the route, they were not able to employ any real route learning strategies (see Farrell et al., 2003). Conversely, in Experiment 1, adults navigated through the maze themselves and may have adopted their own navigational strategy to help them to successfully retrace the route. Previous researchers have shown that teaching route learning strategies can often improve wayfinding. For example, looking back strategies (Cornell et al., 1989), route/survey strategies (Carlson et al., 2010) thinking aloud strategies (Kato & Takeuchi, 2003) and verbal labelling strategies (Darvizeh & Spencer, 1984; Farran et al., 2010) have been shown to improve route learning performance. Given how impressive route learning performance was in Experiment 1 we wanted to investigate whether adults were using a strategy to successfully find their way through this reasonably long maze.

As discussed earlier, employing an egocentric or an associative strategy with numerous choicepoints would be cognitively taxing for participants in Experiment 1 (Golledge, 1987; Hayashi, Fujii, & Inui, 1990; Lingwood et al., 2018; Sameer & Bhushan, 2017). An alternative strategy would be to scan the scene and walk towards a known landmark (a ‘beacon’) and use that landmark as a ‘goal’ to navigate towards. A ‘visual matching’ strategy is an example of a beacon-based strategy that could have been employed to assess if the traveller recognised another landmark before deciding which path to take. In this sense, participants may have decided if they recognised the visual array as being part of the route. According to Wang et al. this ‘guidance’ or ‘visual matching’ strategy is the most effective in an unfamiliar environment and participants are not reliant on explicit memories of the turns or choicepoints of the environment (see also Cornell et al., 1994).

To our knowledge no studies have explored whether adults use a beacon-based ‘visual matching’ strategy when learning a novel route. Furthermore, ‘visual matching’ is not discussed in any theories of route learning (Montello, 1998; Siegel & White, 1975). The aim of Experiment 3 was to explore whether participants would use a ‘visual matching’ strategy in an environment made up of ‘T’ junctions (see figure 4). If participants rely on an associative strategy, they do not need to look down a junction to see if they recognise another landmark before deciding which path to take because the landmark is associated with a motor response (turn left or right). Conversely, if they are relying on a ‘visual matching’ strategy they must look for known landmarks or visual scenes. It was predicted that participants would use a ‘visual matching’ strategy in an environment made up of ‘T’ junctions.



*Figure 4: First-person view of a ‘T’ shaped junction*

**Experiment 3**

**Methodology**

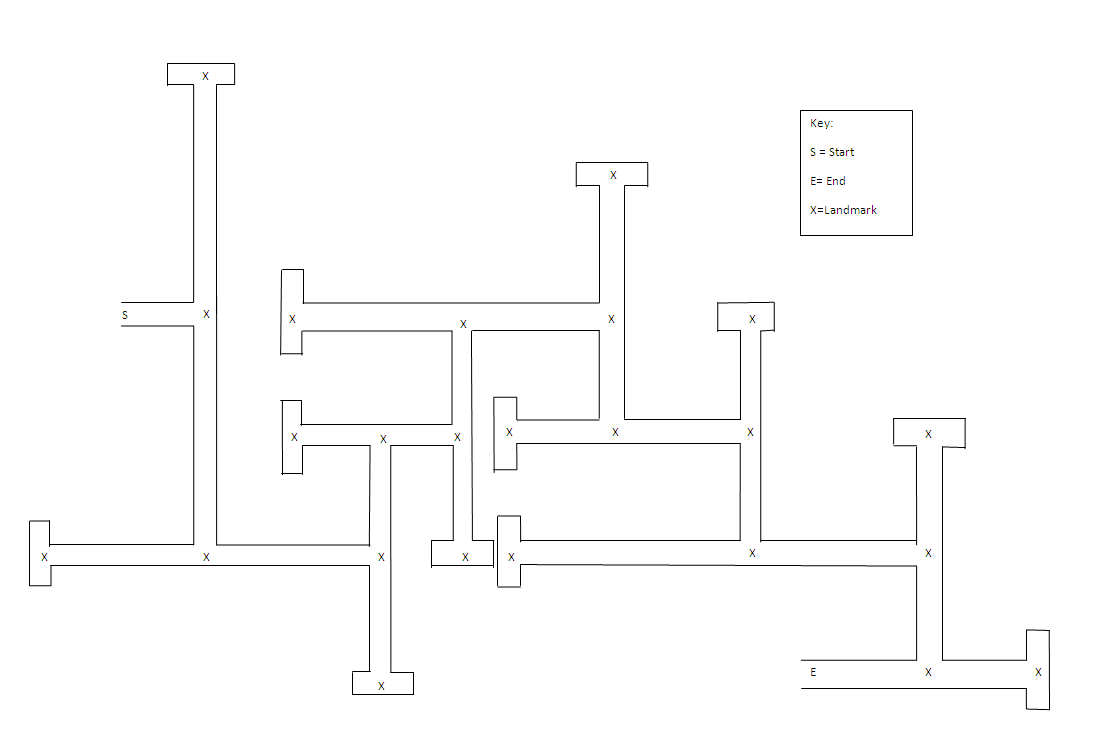
*Participants*

Forty adults were sampled at the University of Anonymised (*M* = 20;5 SD = 3;8), ranging between the ages of 18;0 and 38;5 years. Twenty-two were female and 18 were male. Ethical approval was granted by the University of Anonymised department of Psychology ethics committee.

*Apparatus and materials*

Similarly, to Experiment 1 adults were familiarised with a practice maze.

The brick wall test maze was made up of 12 ‘T’ shaped junctions (see Figure 5). Each junction had two possible directions (a correct path and an incorrect path). The incorrect path always ended in a cul-de-sac. Throughout the 12 ‘T’ shaped junctions, there were seven right correct choices and five left correct choices. All path choices were one of two lengths: short length paths and long length paths. This was because when more than 10 ‘T’ junctions were created, the Vizard software programme would not allow us to keep all the length lines a consistent length without the junctions colliding with one another. This would then create a shortcut in the maze. Nonetheless each pair of correct and incorrect paths were equal with one another ensuring that adults could not use path length as a cue.



*Figure 5: Experiment 3, 12-turn ‘T’ junction maze layout with each X depicting a different landmark*

The maze contained 24 landmarks and the landmarks were chosen from a variety of categories.

*Procedure*

The procedure was identical to the procedure in Experiment 1. Adults were walked through the route and were asked to retrace this route themselves.

*Design*

Similarly to Experiment 1 we measured number of trials to reach learning criterion and the number of errors. We also measured the number of ‘visual matching’ behaviours during the learning phase. Every time participants used the arrow keys to turn left or right to look down a junction, this was coded as a ‘visual matching’ behaviour.

**Results**

In order to answer our research question, we measured the number of errors adults made and crucially, whether or not they displayed ‘visual matching’ behaviours during the learning phase. Adults made few errors (*M* = 0.95, SD = 2.46, range = 0.00 to 11.00) and as a proportional error score this was very small (*M* = 0.02, SD = 0.03). Adults required very few trials to reach the learning criterion (*M* = 0.60, SD = 0.60), range = 0.00 to 3.00) but they frequently displayed ‘visual matching’ behaviours, and looked down junctions during the learning phase (*M* = 11.30, SD = 8.34, range = 3.00 to 35.00).

**Discussion**

The findings from Experiment 3 showed that adults successfully learnt and remembered a 12-turn route made up of ‘T’ junctions, making few errors and requiring few trials to reach criterion. Previous researchers would not have predicted that adults would be able to learn a route of this length (Golledge, 1992; Hayashi et al., 1990) nor would they have predicted that adults would do so by committing so few errors and learning the route so quickly (Siegel & White, 1975). Yet, the findings show that adults could learn a route very quickly having viewed that route just once.

One of the aims of Experiment 3 was to investigate whether adults were using a beacon-based ‘visual matching’ strategy when retracing the 12-turn maze. In line with our predictions we found that adults often used a ‘visual matching’ strategy when retracing the ‘T’ junction maze. For example when approaching a ‘T’ junction the available paths were not immediately visible to adults. In other words, to view other paths adults would need to turn in the maze. We found that adults frequently turned to look down paths to consider which landmarks they recognised from when they were initially shown the route by the experimenter. In these instances, if the landmark they saw was familiar to them they chose to walk down this path. If the landmark was not familiar to them, they chose to walk down the alternative path.

There was considerable variation amongst our participants, however, suggesting that not all participants used a visual matching strategy at every junction. Across all trials, errors ranged from 0 to 11 out of a maximum of 12, the number of additional learning trials required ranged from 0 to 3, and participants used a ‘visual matching’ strategy between 3 and 35 times. Therefore, mean and standard deviation statistics do not necessarily reflect the individual differences in wayfinding within our sample.

**General discussion**

Adults are highly competent at wayfinding, yet little is known about how adults become so good at wayfinding (Waller & Lippa, 2007), particularly in large unfamiliar environments (Kitchin & Blades, 2002). Using VE routes that included up to 15 choicepoints, we found that adults were very good at retracing mazes of this length having been ‘walked’ through the maze only once by the experimenter. In these experiments the majority of adults retraced a route perfectly. On the few occasions that adults were not immediately correct they made few errors and required few additional trials to reach learning criterion. This finding was consistent across all of our experiments and these findings challenged the idea that adults learnt routes in a series of stages after having experienced that route lots of times (e.g., Hart & Moore, 1973; Siegel & White, 1975).

Previous researchers have shown that adults can memorise *some* of the landmarks along a route immediately having seen them only once (Gärling et al., 1981; Ishikawa & Montello, 2006). However, with the exception of Lingwood et al. (2018), until now no studies have shown that most adults can retrace long routes, with up to 15 choicepoints, perfectly having viewed them only once.

In Experiment 2 adults were passively ‘walked’ through a 15 choicepoint maze by the experimenter before being asked to estimate how well they would perform if they were to retrace the route themselves. Adults were inaccurate at estimating how good they would be at learning a 15-choicepoint maze despite the fact that in Experiment 1 most adults learnt a 15-choicepoint maze after a single experience. In Experiment 3 we found that adults learnt a novel route straight away despite only viewing it once and so we considered how adults completed the task. Drawing on Cornell et al.’s (1994) ‘place recognition’ model of wayfinding, we noted that adults often used a ‘visual matching’ strategy when approaching a junction by looking down the available paths at each intersection before choosing a path to walk down.

Wayfinding strategies are not discussed in any theories of wayfinding (e.g., Hart & Moore, 1973; Montello, 1988; Siegel & White, 1975) but we argue that strategies are a key component of wayfinding that should be considered (Jansen-Osmann, 2007). When learning a new route, adults may benefit from attending to landmarks that are near junctions associated with a decision point. If an adult is unsure which way to turn at a particular junction, then he/she should look down each available path in order to scan the scene for familiar landmarks.

*Limitations*

This paper explored how adults developed wayfinding abilities using desktop VEs. VEs allowed us to study wayfinding in a more controlled manner compared to studying wayfinding in the real world where it is almost impossible to manipulate the characteristics of an environment (Jansen-Osmann, 2007). Furthermore the use of VEs allowed us to investigate route learning over repeated trials without participants suffering from physical fatigue commonly associated with real environments (Broadbent et al., 2014; Jansen-Osmann, 2007).

Notwithstanding this, we recognise that there are several proprioceptive and vestibular elements that our participants did not experience, which may be important for route learning (Lokka & Çöltekin, 2019). Additionally, in the current paper, participants did not freely navigate the virtual environments, as they may do when learning a route in the real word. Instead, they were asked to make a series of decisions at intersections. Therefore, whilst there are many advantages of using desktop VEs to study route learning, we acknowledge that there are some aspects of our experimental design that did not emulate route learning in the real world.

The introduction of VEs has allowed researchers to study wayfinding in a whole new manner because they have provided researchers with the opportunity to manipulate variables that cannot be manipulated in a real environment (Blades, 1997; Jansen-Osmann, 2007). The VEs used in this manuscript were purposefully sparse. We did not want to introduce too many confounding variables (e.g., size, type and position of landmarks) given that the basic principles of how adults learn routes were yet to be established (Waller & Lippa, 2007). These findings are based on the layout of just one environment. Additionally, in the VEs we used in the current paper, junctions were made up of two intersections and each junction was visually uncluttered. These types of junctions may be easy to recall in comparison with more visually complex junctions (Asher et al., 2013; Clarke et al., 2013; Klippel et al., 2013; Montello, 2005) Nevertheless, several studies have shown that the use of landmarks does not differ across sparse and rich environments (Farran et al., 2012; Farran et al., 2015). Therefore, future studies could also investigate how the number or saliency of landmarks might influence the number of ‘visual matching’ behaviours when retracing a route.

In addition, for the maze that was used in Experiment 1, only two of the junctions involved a T-junction on approach (i.e., turn left OR turn right, versus continue straight or turn one way). Therefore, theoretically, on some turns, because all of the incorrect paths ended with T-junction cul-de-sacs, participants could use the strategy to "always take the turn before a T-junction." However, counter to this, it is unlikely that someone would discover that strategy for two reasons. First, all participants are only shown the route once, and second, participants are only shown the correct route, from a first-person perspective and so would not have had the opportunity to see the ends of most of the incorrect paths. Whether or not participants would discover this strategy if they saw the birds eye view of the maze prior to retracing the route, would be an interesting avenue for future research. Furthermore, in Experiment 3, we did not restrict participants in using a particular strategy when retracing the route. However, by doing so, this may have been a more stringent method to investigate strategy use. An interesting future study could do this by enforcing either (i) a ‘visual matching’ strategy by asking participants to look down all available paths at each junction before making their decision, or (ii) an associative cue strategy by preventing participants from looking down any available paths at each junction before making their decision.

*Conclusions*

To summarise, these experiments showed that adults were able to retrace a route sometimes immediately even if they had very limited experience of the route. They often used a beacon-based ‘visual matching’strategy when retracing a maze made up of ‘T’ junctions. These findings suggest that adults may not learn routes in the manner proposed by current theories of wayfinding.

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1. We define choicepoints as straight ahead, left or right turns. [↑](#footnote-ref-1)
2. Relatedly, at an outreach event hosted at the Science Museum in Anonymised, we tested a large sample of adults (*N* = 310) and found that whilst men and women showed similar performance in learning 9- and 12-turn mazes, women were not as confident as men when asked to rate their own wayfinding abilities. [↑](#footnote-ref-2)