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THE EFFECT OF USING TECHNOLOGICAL TOOLS ON URBAN NAVIGATION:

A mixed-methods study on wayfinding behaviour in Newcastle Upon Tyne, UK

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ABSTRACT

Existing wayfinding literature has established strong links between the built environment and navigation in urban context (Allen, 2004; Raubal, 2008). These studies often assume that full cognitive attention is directed towards the task. However, in our modern society, engaging with various technological tools, such as smartphones, during wayfinding has become prevalent. The aim of this study is to assess how interacting with such technological tools during navigation influences wayfinding and spatial knowledge acquisition by employing a mixed-methods approach. 8 participants, assigned into 2 groups with access to technological tools being the differentiating factor, conducted a wayfinding task in Newcastle upon Tyne, UK. Upon completion, they participated in a post-activity survey and cognitive mapping activity. The street network configuration was analysed with various syntactic measures. The 'predicted route', determined by the most connected segments between origin-destination, was compared against the selected routes to identify differences in route choice behaviour. In addition, spatial knowledge acquisition across two groups was investigated through thematic analyses of surveys and maps. The results showed that individuals without access to technological tools displayed higher environmental awareness, producing cognitive maps which were richer in qualitative data. Interestingly, this did not translate into the selection of the most direct route. Analysis of cognitive maps suggested that these participants consciously avoided segments with specific environmental affordances (i.e., increased pedestrian densities). This study contributes towards existing wayfinding knowledge in the built environment by expanding our understanding on how using technological tools during navigation influences wayfinding behaviour and spatial cognition.

KEYWORDS

Wayfinding, Space Syntax, Technological Tools, Cognitive Mapping, Post-activity Surveys

1. INTRODUCTION

Technological tools, such as personal smartphones, are vital objects which assist people throughout their daily lives to the extent that they can be described as indispensable in a modern, technologically dependant society. However, as a result of this, it is also evident from observations in our urban environment that the human race is becoming ever more introverted, often prioritising, and relying upon, instantaneous handheld information from these technological tools over the spatial information offered by the environment. This poses an issue in urban navigation because wayfinding by definition makes explicit the interaction between attributes of both the traveller and the surrounding environment (Allen, 2010). Gibson (1979) expands upon the attributes of the environment, in which he coins the term 'Affordances' to describe the measurable properties of the environment and how they offer possibilities for action to be extracted by the traveller, through a process of 'perception'. It is argued that these affordances in the environment are able to help or hinder human wayfinding (Athus & Passini, 1990; Passini, 1984).

Existing wayfinding literature has established strong links between the built environment and navigation in urban context (Allen, 2004; Raubal, 2008). It is shown that the way the urban network is configured is significantly associated with wayfinding performance, evaluated through route choice behaviour (Dalton, 2003; Hillier & Iida, 2005), cognitive map analysis (Allen, 2010), and landmark identification (Lynch, 1960). These studies often assume that full cognitive attention is directed towards the task. However, in a constantly changing world, engaging with various technological tools, such as personal smartphones to talk or listen to music, during wayfinding has become prevalent. While it is acknowledged that such technological tools have the potential to assist wayfinding, as eluded to by Kottmann (2000), it is also postulated that they can simultaneously inhibit our cognitive interaction with the environment when used in dual-task conditions (Lin & Huang, 2017). Such examples show that completing cognitive tasks while walking is not only dangerous (Lennon, et al., 2017), but also show dysfunction of environmental interference capabilities (McFadyen, et al., 2017). Hence, an in-depth understanding of the effects of using technological tools[1] during navigation on wayfinding behaviour and spatial knowledge acquisition could provide significant input to theory (i.e., existing knowledgebase concerning pedestrians' navigation behaviour) and to practice (e.g., post-pandemic planning and re-vitalisation of city-centres).

[1] In this study, the term 'technological tools' is used to reference items including devices such as mobile phones, headphones, and smart-watches, which are frequently used in parallel to everyday tasks, such as wayfinding. Note: while most of these devices are capable of providing GPS assistance during wayfinding, this function was not utilised in this study.

2 THEORY

Wayfinding is a task that intrinsically facilitates the action of exploration. Within existing literature, human wayfinding has been categorised into three distinct types, these are:

> *"travel with the goal of reaching a familiar destination, exploratory travel with the goal of returning to a familiar point of origin, and travel with the goal of reaching a novel destination"* (Raubal, 2008).

These descriptions are expansions of the terms "commutes, explores, and quests" (Allen, 2004), which are based upon their purpose, but are condensed to their foundations, to allow a simple overview of what is an otherwise complicated process. Allan (2004) expands further to explain the "means most frequently used to accomplish these tasks", labelling the methods as "*wayfaring"* techniques. Throughout subsequent papers, Allen (2004; 2010) has compiled a list of common *wayfaring* techniques which allow wayfinding to be possible; these are: "Repetition of Locomotion", "Piloting", Path Integration", and "Navigation by Cognitive Map".

2.1 Commute, Explore, and Quests

The commute, or "travel between two places known to the traveller" (Allen, 2004), is the most common type of wayfinding task. It is described as "goal-directed" and is "so commonplace" (Allen, 2010) that travellers participating in this type of wayfinding can be classified as "experts" (Woollett & Maguire, 2010) in the environment, and utilise the wayfaring technique of *repetition of locomotion* to navigate. Taxi drivers display the highest degree of expertise in this form of wayfinding, recounting "extremely detailed [accounts] of what they had been thinking during wayfinding" (Spiers & Maguire, 2008). The technique of *repetition of locomotion* builds greater familiarity of the environment, resulting in more successful wayfinding attempts. This is reinforced by Raubal (2008), who states that familiarity within the environment "has a big impact on wayfinding performance". The key measure for *commuting* is "efficiency, that is, time spent in transit weighted by the effort expended" (Allen, 2004). The *explore* is orientated about familiar points of origin/destination with the technique of piloting utilised to stimulate movement between landmarks to develop further understanding (Allen, 2004). A successful 'explore' is subjective but is measured in relation to quantity of novel information gained about the environment. Conversely, the *quest* involves the action of travelling from a familiar place of origin to a novel destination (Allen, 2010). This is usually a place which is known to exist but has not been visited by the traveller. Sources agree that the knowledge of this novel destination - and how to get there- is usually derived from "a cognitive transaction; an individual who needs information seeks it from a knowledgeable source" (Allen, 1997), or gained from symbolic information (Raubal, 2008), such as a cognitive map (Allen, 2004).

2.2 Planning, Route, and Movement

It is evident that the wayfinding process "is a complex activity, [and is] usually divided into several tasks" (Timpf & Sabine, 2002). Earlier research suggests that it actually requires at least three stages: planning, route instructions, and moving" (Timpf, et al., 1992). *Planning* is the action of understanding the destination, which in turn, will inform the type of wayfinding activity to be utilised. Subsequently, the required environmental information needed to successfully complete the wayfinding attempt can then be determined. Depending on both the complexity and the familiarity of the environment, the traveller may require greater levels of these techniques to ensure reaching the destination. Finally, to complete the wayfinding attempt successfully, the traveller must navigate through the environment, while ensuring efficient cognitive perception of the relevant environmental information.

2.3 The Environment and The Traveller

In the concept of wayfinding there are - as made explicit through the discussion of the "inseparable pair" (Gibson, 1979) -two individual parties involved: the environment and the traveller. The environment can be referred to as "material provided to the traveller" (Timpf & Sabine, 2002), and can include information such as buildings, plans, or "measurable aspects of the environment (Raubal, 2008) (e.g., affordances). Meanwhile the traveller is a "mobile individual superimposed on that system" (Hillier, et al., 1987).

Space syntax methodology provides a systematic and objective tool to quantify the built environment in which the traveller navigates (Hillier & Hanson, 1984; Hillier, 1976; Penn, 2003). Key studies by Hillier et al (1987) provide precedent for walking along predetermined routes and recording data (encounter rates) relevant to that route. Hillier and Iida (2005) have also demonstrated strong correlations of pedestrian densities against syntactic measures in four London areas using an effective empirical research design which combines both quantitative and qualitative methods. More recently, and locally applicable, similar empirical research by Vialard and Torun (2019) in Newcastle upon Tyne has shown a significant correlation between global measures (integration and metric reach at 1km) and pedestrian flows at the segment-level and proving that "people occupy the spaces which have the increased potential of movement within the entire network". Other relevant examples include studies which utilise agent-based methods in order to hypothesise then test these against human situations (Kuipers, et al., 2003), or using space syntax methodology followed by empirical research to evaluate its consistency (Nenci & Troffa, 2006).

While it is possible to predict probable travel behaviour from this data, it is the task of the traveller to digest the environmental information as part of a cognitive process and produce their own viewpoint "to be held by [the] individual" (Lynch, 1960), which will subsequently inform environmental behaviour. "Different people can have different perspectives on the same objective reality" (Timpf & Sabine, 2002), hence, producing distinct images of the same environment. Turner (2020) reinforces this view, stating that "each of us has our own unique relationship with the city, how we see it, or not, and how we move through it, or not", proving that an identical set of data in a given environment will likely be extracted and interpreted differently by individual travellers. These perspectives can be informed by a variety of factors which are subjective to the traveller, including societal backgrounds, values, and extent of knowledge. This can manifest itself differently between travellers, resulting in "cognition and behaviour [which has been] influenced" (Allen, 2010) by these varying factors. Therefore, while space syntax provides a robust methodology to estimate predicted patterns of human behaviour, the underlying theory relies upon the traveller's ability to absorb the available information and respond accordingly. However, whether and how interacting with technological tools during navigation affects travellers' wayfinding behaviour and spatial knowledge acquisition remains unclear.

Empirical research has highlighted acquiring and studying individual thoughts and processes as a form of data in wayfinding literature (Golledge, 2003) (Bruns & Chamberlain, 2019) (Padgitt & Hund, 2012). Notably Lynch's (1960) studies, which brought wayfinding into the realm of architecture, utilised the approach of interviews to enable participants to retrospectively perform mental trips across the city, highlighting observations and landmarks along the way. Other studies with similar objectives employed methods of "static tasks" (Spiers & Maguire, 2008), such as sketching maps retrospectively. Both these methods essentially aim to test the participant's ability to extract important information which is unique to their personal image of the environment. Hence, it is argued that people's travel behaviour is not shaped merely by the physical environment but also depends on the spatial knowledge or mental representation of the physical environment acquired by the individual (Ahmadpoor & Shahab, 2019).

2.4 Research Objectives

As of this writing, it remains unclear how engaging with various technological tools, such as personal smartphones, during wayfinding influences people's navigation behaviour and spatial knowledge acquisition. Although wayfinding literature contains a plethora of studies on humans' travel behaviour and strategies employed during navigation in the built environments, the existing literature typically assumes the traveller is entirely focused on the task of wayfinding; whereas it is increasingly evident that this is not the case in our modern society due to the prevalence of technological tools in everyday life, such as navigation. To date, research on the interplay between the built environment (including street network design and landmarks) and technological tools is limited and hence, how travellers' wayfinding behaviour and spatial knowledge acquisition varies whether they use such tools is not well understood.

Considering the above-mentioned studies, this study aims to contribute to the existing but limited body of work regarding the effects of using technological tools during navigation on wayfinding.

The main objective of this study is to assess how interacting with such tools during a wayfinding task influences travel behaviour (i.e., route choice) and spatial knowledge acquisition in an urban environment by employing a mixed-methods approach, synthesizing space syntax analyses, post-activity surveys, and cognitive mapping.

3 DATASETS AND METHODS

3.1 Case Study Environment

The environment that forms the basis for this study is the city centre of Newcastle upon Tyne, UK. Newcastle provides a pedestrian friendly city centre which offers a large variety of amenities orientated around a pedestrianised high street. Furthermore, a large proportion of vehicular traffic is directed around the periphery of the city utilising main infrastructure axis such as the Central Motorway (A167M), Great North Road (leading to Percy Street and Newgate Street), and Westgate Road (leading to Mosely Street). These axes define key edges around the city centre, with districts such as Civic Centre and the university campuses providing further distinction to the pedestrian core (Figure 1). This defined zone equates to approximately 400m radius, which is generally considered a suitable distance for walking (Perry, 1929), and aligns the study well with previous studies within the city centre (Vialard & Torun, 2019).

Figure 1: Case study area ('Walkable' City Centre Zone) within Newcastle upon Tyne, UK.

The study identified an origin and destination location within the case study area to facilitate a wayfinding task. The origin/destination pair was selected to provide a fine balance of adequate distance, route choice, and environmental complexity without being overbearing to participants. They are also relatively well known, safe, and central locations which provide sufficient choice for potential movement and variation between the two points. Figure 2 demonstrates these locations on the city map.

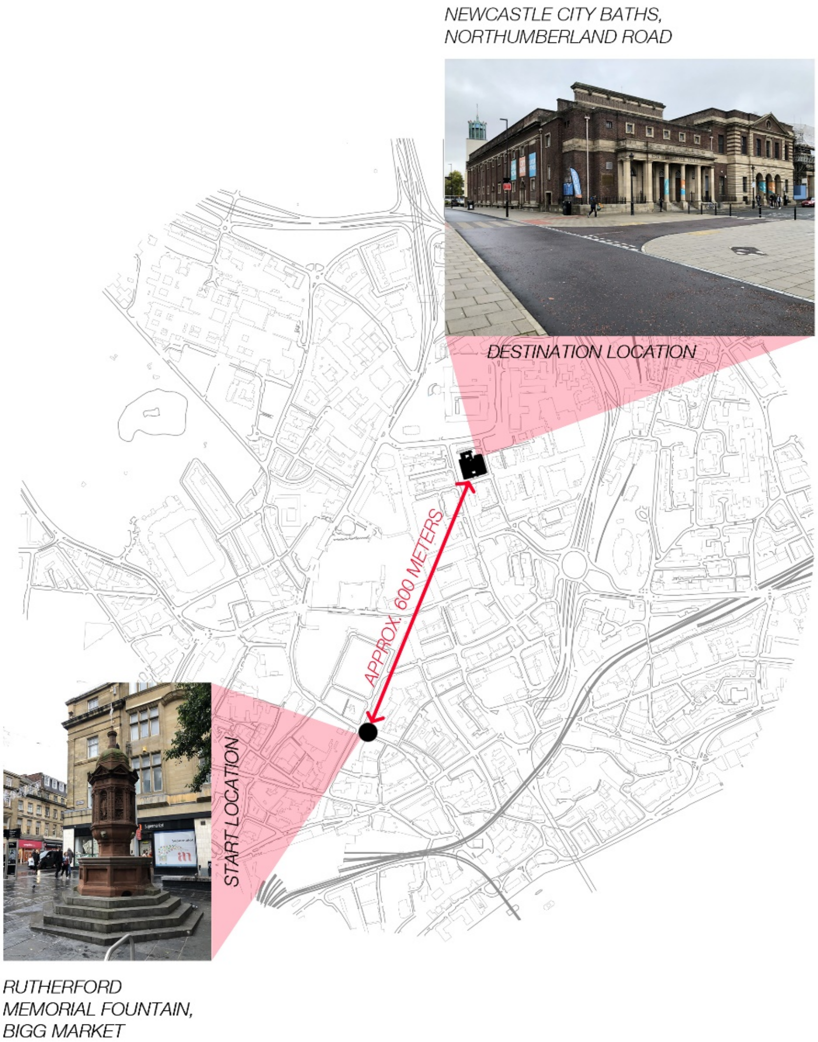

Figure 2: Origin and Destination Locations within the case study area.

3.2 Instrumentation

8 participants, who are moderately familiar and/or familiar with the study area, were asked to navigate through Newcastle city centre between the identical origin/destination pair. The participants were supplied with the origin/destination names only, with the exact route between these points deliberately left to the individual to determine based on their existing familiarity of the area. The participants were randomly and evenly assigned into two groups. Group 1 was asked to complete the task without using any technological tools (e.g., engaging with phone), while Group 2 was asked to deliberately use such tools, except for a GPS device. Route choice and total travel time were recorded by the travellers retrospectively by drawing the travelled route on a pre-defined map and manually recording the travel time. Upon completion of the task, participants were asked to draw a cognitive map of their travelled route on a blank A4 sheet, providing as much information (i.e., street names, landmarks) as they could remember. This

mapping activity was focussed on measuring the spatial knowledge acquisition of participants during urban navigation. Participants were then invited to complete a post-activity survey that consisted of 9 questions: the first 3 questions included demographic characteristics (age, gender, and occupation); following 3 questions asked them to report their travel time, weather condition at the time, and whether they had a pre-determined route planned before starting their urban navigation; and the remaining 3 questions inquired about why they selected that particular route, whether and why they chose to deviate from their pre-determined route, and asking for general comments regarding their wayfinding experience. The aim of this qualitative data collection phase was to gather more evidence relating to the cognitive processes of the participants during the wayfinding task.

3.3 Street Network Configuration

Street network configuration of the entire city was evaluated by using Angular Segment Analysis (ASA) measures of Segment Angular Integration (AIN) and Normalised Angular Choice (NACH) in DepthmapX software (2010). Segment Angular Integration represents the "to-movement potential" (Hillier, et al., 2012) of a space through measuring how accessible –or central- a segment is from all other segments in the system. The incorporation of the factor of least angular distance distinguishes this measure from standard 'integration' to provide a more accurate indication of the cognitive effort –or 'cost' (Turner, 2005)– to reach a destination segment. NACH, on the other hand, represents the "through-movement potential" (Hillier, et al., 2012) -or "betweenness"- of segments within a system. The measurement calculates the shortest (angular) path between each pair and summarises the quantity of movement as a through-road. Normalised choice involves dividing total choice by total depth for each segment, hence accounting for the size of the system (Hillier, et al., 2012). This measure is considered more accurate at predicting pedestrian movement than integration because it is argued that people perceive the urban network geometrically (Hillier & Iida, 2005), therefore less angular change of direction is perceived as being less complex.

In this study both measures were calculated for radius *n* as this radius has been suggested to show the highest correlation with pedestrian movement within Newcastle City Centre area (Vialard & Torun, 2019).

3.4 Analysis

A 'predicted route' between the origin/destination pair was identified by overlapping the segments with top 10% AIN and NACH values and selecting those segments (n=35) with the greatest frequencies of overlap along the route (Figure 3). This analysis identified a primary structure of street network which was assumed to be theoretically most likely chosen during wayfinding based on previous literature (Orellana & Guerrero, 2019) (van Nes & Yamu, 2021). The 'predicted route' and individual routes were then overlapped and compared to identify differences in route choice behaviour across two groups of travellers.

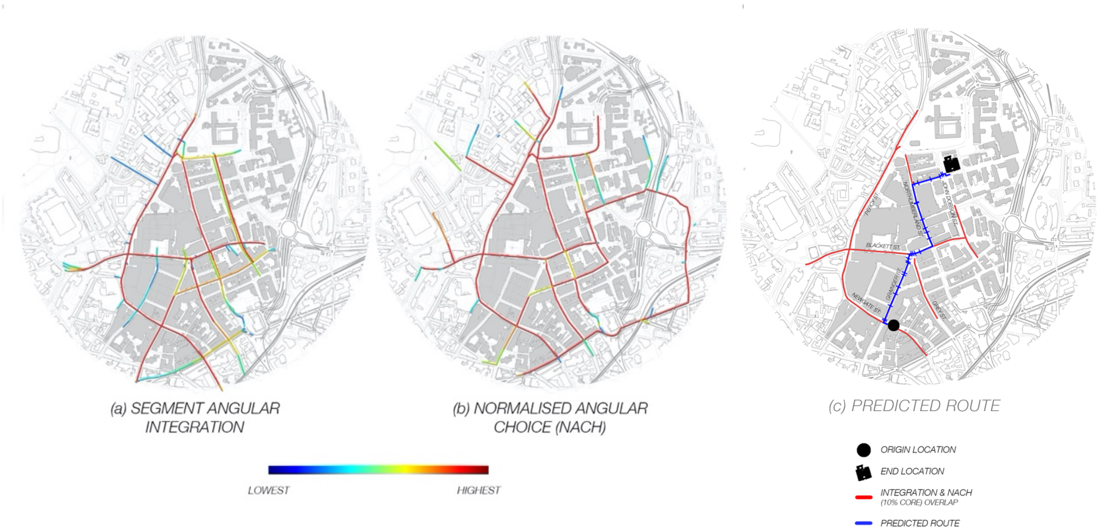

Figure 3: Syntactic maps showing 10% core values for AIN (a) and NACH (b), and (c) “predicted route” based on the overlap of these segments.

Finally, to understand the underlying reasons of certain behavioural patterns displayed during wayfinding, the qualitative data collected through post-activity surveys and cognitive mapping was thematically analysed and compared across the sample groups. This follows Lynch’s (1960) studies which state that while individual ‘images’ can be important, it is the ‘public images’ which are most valuable since the environment is to be used by many people. Primary themes and sub-themes were identified and the obtained data (keywords) for each category was quantified in terms of the number of recordings.

4 RESULTS

4.1 Travelled Routes, Time, and Distance

Travelled routes, compiled together, between the origin and destination are presented in Figure 4. Darker colours indicate an increased overlap. Table 1 describes the average travel times and distances for both groups.

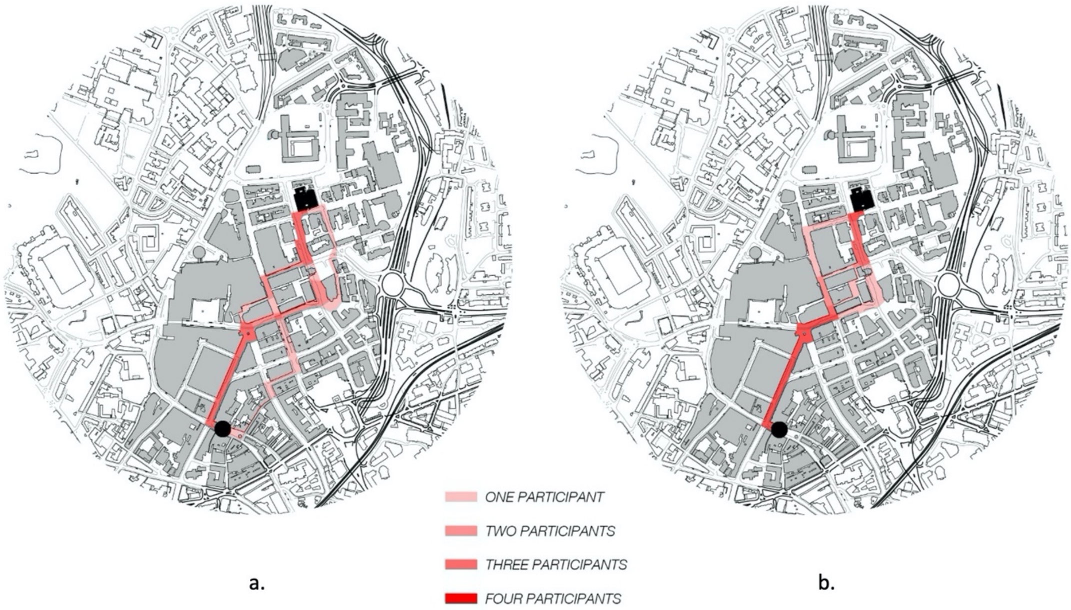

Figure 4: Compiled travelled routes for (a) Group 1-participants without any technological tools, and (b) Group 2-participants using technological tools.

GROUP 1			
PARTICIPANT ID LETTER	PRESENCE OF TECHNOLOGY	TOTAL TIME FOR WAYFINDING TASK	DISTANCE OF TRAVEL (Km)
A	N	00:09:55	0.98
B	N	00:09:58	0.82
C	N	00:07:49	0.79
D	N	00:10:51	1.06
Group Average		00:09:38	0.9125

GROUP 2			
PARTICIPANT ID LETTER	PRESENCE OF TECHNOLOGY	TOTAL TIME FOR WAYFINDING TASK	DISTANCE OF TRAVEL (Km)
E	Y	00:09:14	0.82
F	Y	00:07:52	0.77
G	Y	00:08:12	0.82
H	Y	00:08:16	0.8
Group Average		00:08:23	0.8025

Table 1: Individual and average travel times and distances for Groups 1 and 2.

It is clear from Table 1 that Group 2, on average, completed the wayfinding task quicker, with an average time of 8:23 minutes, as opposed to Group 1’s average of 9:38 minutes. Participants in Group 1 did however produce both the quickest (7:49) and longest (10:51) travel times by participants C and D, respectively. Although not considered essential in this study, the average distance travelled by both groups is also calculated using Google Earth. Similarly, Group 2 on average recorded a shorter distance (0.8km), travelling 0.11km less than Group 1 on average.

4.2 Comparison of Predicted and Actual Routes

Figure 5 demonstrates the individual selected routes (in red) by participants in Group 1 (with no access to technological tools) and Group 2 (those using technological tools), overlapped with the ‘predicted route’ (in blue). Darker colours indicate an increased overlap.

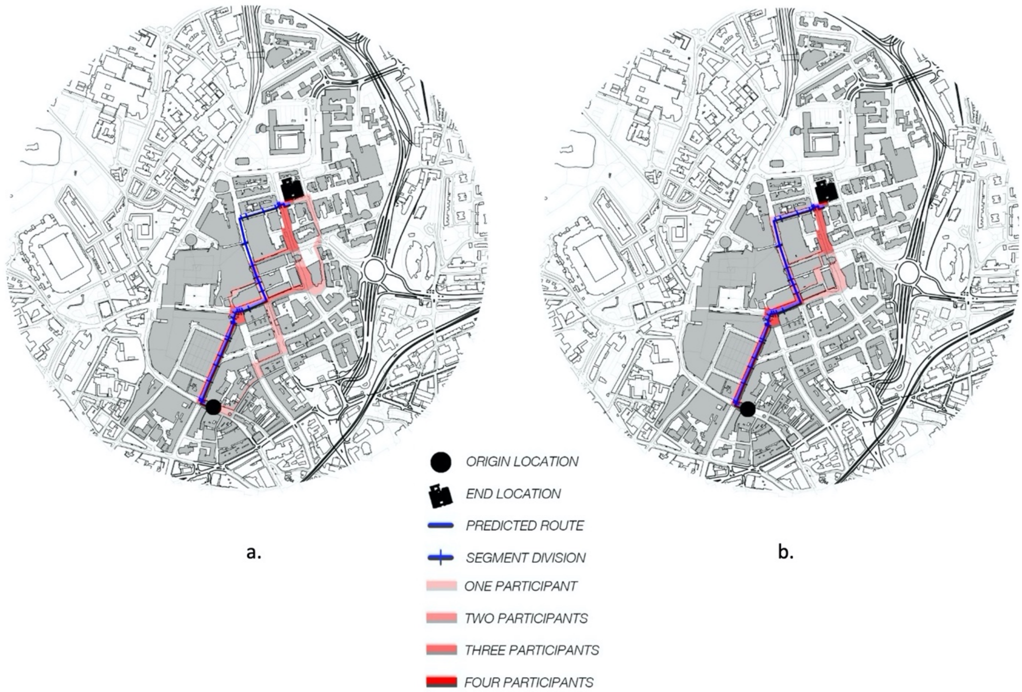

Figure 5: Map showing correlation of Group 1 routes against predicted route.

Tables 2 and 3 quantify the above maps by applying a value to each segment of the ‘predicted route’ to reflect whether that segment was selected by the participants during navigation. The value of 1 was allocated to segments which are chosen and 0 (shown as ‘-‘) to those which are not. The percentage of segments selected along the ‘predicted route’ were then calculated and averages were produced for individuals and the Groups. The highest and lowest AIN and NACH value segments are also highlighted in red and blue respectively.

SEGMENT NUMBER	NORMALISED ANGULAR CHOICE	ANGULAR INTEGRATION	PREDICTED ROUTE SEGMENT SELECTED? (1 = yes, - = no) PART. A	PART. B	PART. C	PART. D	SEGMENT TOTAL	SELECTED %
1	6.2249224	881.016785	-	1	1	1	3	75%
2	5.771621	864.366882	-	1	1	1	3	75%
3	5.771635	865.402039	-	1	1	1	3	75%
4	5.771681	865.402039	-	1	1	1	3	75%
5	5.784574	865.640259	-	1	1	1	3	75%
6	5.827076	865.648315	-	1	1	1	3	75%
7	5.337873	823.257141	-	1	1	1	3	75%
8	5.359608	823.274414	-	1	1	1	3	75%

9	5.332034	822.93158	-	1	1	1	3	75%
10	5.324118	822.948853	-	1	1	1	3	75%
11	5.321692	827.647034	-	1	1	1	3	75%
12	5.320873	827.64563	-	1	1	1	3	75%
13	4.807677	816.529053	-	-	1	1	2	50%
14	4.870164	816.597595	-	-	1	1	2	50%
15	6.26418	924.294434	-	-	1	1	2	50%
16	6.264341	926.730835	-	-	1	1	2	50%
17	6.128502	922.447998	-	-	1	1	2	50%
18	6.186702	936.490295	1	-	1	1	3	75%
19	6.187027	934.207336	-	-	1	-	1	25%
20	5.91111	855.880127	-	-	1	-	1	25%
21	5.90799	854.590637	-	1	1	-	2	50%
22	5.906304	852.522583	-	1	1	-	2	50%
23	5.888012	848.988953	-	-	-	-	0	0%
24	5.872614	848.685608	-	-	-	-	0	0%
25	5.858355	849.263611	-	-	-	-	0	0%
26	5.845865	845.589539	-	-	-	-	0	0%
27	4.629297	750.393494	-	-	-	-	0	0%
28	4.600254	750.393494	-	-	-	-	0	0%
29	4.569081	750.237915	-	-	-	-	0	0%
30	4.448737	750.247559	-	-	-	-	0	0%
31	3.937518	727.988708	-	-	-	-	0	0%
32	3.864096	737.316833	-	-	-	-	0	0%
33	3.88846	737.202271	-	-	-	-	0	0%
34	5.606595	853.92395	-	-	-	-	0	0%
35	4.72592	749.167786	1	1	1	-	3	75%
TOTAL	N/A	N/A	2	15	23	18	58	
%	N/A	N/A	5.71%	42.86%	65.71%	51.43 %	41.43%	
AVERAGE	5.385046647	832.7604353						

Table 2: Segment choice quantified for Group 1.

Table 2 shows that there is a large degree of variation between the participants' segment selection and the 'predicted route' ranging from 5.71% to 65.71% overlap between individual routes and 'predicted route'. Average overlap of 41.43% across Group 1 presents an accurate representation of this variation. While this is a relatively a low (below the mean) frequency of overlap with the 'predicted route', 3 participants selected the highest value AIN segment during navigation while the highest NACH value segment along the 'predicted route' was also selected by 2 participants. There is also a high frequency of selection (75%) of the first 12 segments along the 'predicted route' by participants. This section of the route captures the immediate surroundings of Grey's Monument, the city's most prominent landmark within the city centre. The NACH and AIN values start to diminish after segment 20, until the minimum is reached at segments 31, 32 and 33 respectively, which were not selected by any participants.

SEGMENT NUMBER	NORMALISED ANGULAR CHOICE	ANGULAR INTEGRATION	PREDICTED ROUTE SEGMENT SELECTED? (1 = yes, - = no)				SEGMENT TOTAL	SELECTED %
			PART. E	PART. F	PART. G	PART. H		
1	6.2249224	881.016785	1	1	1	1	4	100%
2	5.771621	864.366882	1	1	1	1	4	100%
3	5.771635	865.402039	1	1	1	1	4	100%
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6	5.827076	865.648315	1	1	1	1	4	100%
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11	5.321692	827.647034	1	1	1	1	4	100%
12	5.320873	827.64563	1	1	1	1	4	100%
13	4.807677	816.529053	1	1	1	1	4	100%
14	4.870164	816.597595	1	1	1	1	4	100%
15	6.26418	924.294434	1	1	1	1	4	100%
16	6.264341	926.730835	1	1	1	1	4	100%
17	6.128502	922.447998	1	1	1	1	4	100%
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29	4.569081	750.237915	1	-	-	-	1	25%
30	4.448737	750.247559	1	-	-	-	1	25%
31	3.937518	727.988708	1	-	-	-	1	25%
32	3.864096	737.316833	1	-	-	-	1	25%
33	3.88846	737.202271	1	-	-	-	1	25%
34	5.606595	853.92395	1	-	-	-	1	25%
35	4.72592	749.167786	1	1	1	1	4	100%
TOTAL	N/A	N/A	35	20	19	23	97	
%	N/A	N/A	100%	57.14%	54.29%	65.71 %	69.29%	
AVERAGE	5.385046647	832.7604353						

Table 3: Segment choice quantified for Group 2.

Table 3 shows that participants in Group 2 -those engaging with technological tools- selected a higher % of segments along the ‘predicted route’, both as individual participants and as a group (69.29%). % overlap between the individual travelled segments and the ‘predicted route’ ranges from 100% (very strong) to 54.29% (moderate). Similar to the trend in Group 1, the frequency of segment selection is initially high, which begins to diminish starting from segment 19. It is interesting that from this segment on all 4 participants selected unique routes. Surprisingly, 3 of these participants then reconverged on the later section of John Dobson Street (segment 35), with the other participant committing fully to the ‘predicted route’ which defines Northumberland Street as the main Northern axis towards the destination.

From the results of the analysis presented above, it is clear that Group 2 followed the ‘predicted route’ more closely compared to the other group, preferring segments with increased connectivity values. This is illustrated by an increased %overlap (69.29% compared to 41.43% overlap) but is also reinforced by a shorter average travel distance (0.8km compared to 0.9km). With the exception of participant D, all participants approached the destination by selecting segment 35. This could be due to the enhanced pedestrian-oriented characteristics (e.g., larger sidewalk width) offered by this segment or due to the fact that it requires the least angular change of direction from the origin, hence representing less cognitive ‘cost’ or effort required to complete the task. Another interesting finding is that the first 18 segments along the ‘predicted route’ were selected by the majority of participants in both groups. This section of the ‘predicted route’ includes segments with the highest NACH and AIN values.

4.3 Post-Activity Surveys and Cognitive Mapping

Two primary themes, namely ‘static element’ theme and ‘journey specific’ theme, were identified through the analysis of post-activity surveys and cognitive mapping. ‘Static element’ theme included district/areas, streets/street names, buildings/structures, shops/restaurants, and landmarks as sub-themes. ‘Journey specific’ themes included environmental properties, sights/interactions, experience/feeling, and sound as sub-themes.

	STATIC/NETWORK ELEMENTS										JOURNEY SPECIFIC ELEMENTS								
	DISTRICT / AREAS	TOTAL	STREETS / STREET NAMES	TOTAL	BUILDINGS / STRUCTURES	TOTAL	SHOPS / RESTAURANTS	TOTAL	LANDMARKS	TOTAL	ENVIRONMENTAL PROPERTIES	TOTAL	SIGHTS / INTERACTIONS	TOTAL	EXPERIENCE / FEELING	TOTAL	SOUND	TOTAL	GROUP TOTALS
PARTICIPANT A	City West (Home), China Town, Quayside, University Campus, Civic Centre,	5	Northumberland St, John Dobson St, Cuts to university campus recorded (x2)	4		9	Five Guys, Five Swans, Costa, Hustlers Pool, Bike Shop, Nail Shop, Primark, New Look, Next, Tiger Tiger, Second Hand Shops, Creams, Beer Keller, Vintage Shops, Pleased to Meet You, Harry's Bar, Illegitimate, Takeaway Shops on Bigg Market, Beehive, Miller & Carter, Bijoux, Fat Hippo	23	Grey's Monument, Statue (Origin) with steps,.	2	Steps to statue, Cobbled Streets, No car zone next to Theatre Royal, Wobbly Paving Slabs	4	Pidgeons next to start, Parked Cars on Bigg Market and side of Theatre Royal, Traffic Lghts/Crossings shown in key locations, Northumberland St very busy, Buses on route	5					52
PARTICIPANT B			Bigg Market	1	Fenwicks, Book Shop, Church, City Pool, City Hall	5	Nail Bar, TJ Hughes, Restaurant, Botanist, H&M, Flannels., Size,	7			Crossing to cross at, Scaffolding in path (had to walk around it on road),	2	Homeless man in doorway, New Nail Shops, Xmas gnomes in doorway, Sale in Size, Steak & Chips on menu, Woman with Yellow Umberella, Menu too small, Guy with Drums (Not Playing), New Flannels and Size opening soon, Silver disc in pavement (some missing)	9	Anxiety - Man crosses infront of bus (Close Call)	1	Street Preecher with microphone (Very Loud)	1	26
PARTICIPANT C			Grainger St, Northumberland St, Saville Row	3	City Hall	1	Start Fitness, TK Max, Greggs	3	Rutherford Memorial Fountain (Origin), Grey's Monument	2			Lots of shoppers on Northumberland St, Long wait to cross at Saville Row.	2	Ambient (x2), Quiet (x2), Claustraphobic, Anxiety about Mask,	6			17
PARTICIPANT D	Eldon Square, 'Hippy Green', University, Time Square,	4	Bigg Market, Market St, Northumberland Street, John Dobson St,	4	Old Barclay's Bank, City Hall, Laing Art Museum,	3	Maplin, Charles Grey, Hotel Chocolate, Five Guys, Hair Dressers,	5	Grey's Monument	1	Pedestrian Crossing, car park (x2)	3	Popup stall selling crisps, Buses at bus stop (people also in bus stop), Strawberry (Fruit & Veg) Stall, Pedestrians stood against wall, People crossing road, People walking slow, cars parked.	7	Annoyed at people walking slow	1	Xmas songs at Charles Grey, Workmen on roof of City Hall	2	30
GROUP TOTALS	9		12		18		38		5		9		23		8		3		125
GROUP AVERAGES	2.25		3		4.5		9.5		1.25		2.25		5.75		2		0.75		

	STATIC/NETWORK ELEMENTS										JOURNEY SPECIFIC ELEMENTS								
	DISTRICT / AREAS	TOTAL	STREETS / STREET NAMES	TOTAL	BUILDINGS / STRUCTURES	TOTAL	SHOPS / RESTAURANTS	TOTAL	LANDMARKS	TOTAL	ENVIRONMENTAL PROPERTIES	TOTAL	SIGHTS / INTERACTIONS	TOTAL	EXPERIENCE / FEELING	TOTAL	SOUND	TOTAL	GROUP TOTALS
PARTICIPANT E			Grainger St, Northumberland St,	2	Metro Station	1	McDonalds, CEX, Subway, Greggs, Burger King, Natwest Bank, KFC, Card Factory, Barclays , City Tavern, Frankie & Bennys, Primark.	12	Grey's Monument	1			Northumberland street very busy. Street wardens controling which side you walk.	2					18
PARTICIPANT F	To Train Station	1	Bigg Market, Northumberland St	2	The Stack, Newcastle Library, City Baths, the Gate, John Dobson underpass	5	McDonalds	1	Grey's Monument	1	Easy to cross road due to no car zone (buses and Cyclists only)	1	Street wardens at bottom of Northumberland St, often Police presence. Person urinating in phonebox	3	Uneasy (not nice environment)	1			15
PARTICIPANT G			Blackett Street, Northumberland St, Saville Row	3	The Stack, Bollards to bottom of Northumberland St, Library	3	Yo-Sushi, TJ Hughes, Five Guys	3	Grey's Monument	1	Crossroad/traffic lights on John Dobson St, Cycle Lane	2	TJ Hughes Open, Shops on Blackett St shut, Library was empty/quiet, Northumberland St was fairly quiet, Service entrance to shops, Family at traffic lights	6	Considers the route taken to be quiet.	1			19
PARTICIPANT H			Northumberland St	1	Monument (Origin), City Baths	2	McDonalds, HSBC, Goldsmiths, White Stuff, Fat Face	5	Grey's Monument	1			Monument (origin) is unusal in shape, 'Friendly' homeless man, Busker (x3), People queuing for shops, People standing at bins smoking/drinking coffee, Goldsmiths gold statue, Christmas Decorations in place (not switched on), Different styles of face mask	10	Grey's Monument is imposing	1			20
GROUP TOTALS	1		8		11		21		4		3		21		3		0		72
GROUP AVERAGES	0.25		2		2.75		5.25		1		0.75		5.25		0.75		0		

Figure 6. Table showing thematic analysis of (left) Group 1 recordings, and (right) Group 2 recordings.

Figure 6 shows participants' environmental recordings, which were then summarised per sample group to find the averages for each theme identified. The top section highlights static data themes, and the bottom shows journey specific data.

Comparison of the tables shown in Figure 6 indicates that in total Group 1 participants recorded 53 more observations, equating to 174% more data in total, than the participants in Group 2 regarding their wayfinding experience. While the 'Shops/Restaurants' sub-theme within the 'static elements' theme has the highest value across both groups, Group 1 massively outperformed Group 2 by a value of 4.25 (a greater total of 181%). The fewer recordings were also consistently observed across both groups for the 'Landmark' sub-theme, with Group 1 recording slightly higher at 1.25 average entries, as opposed to an average value of 1 for Group 2. 'Journey specific' theme follows a similar trend with the 'static elements' theme, with Group 1 recording more entries compared to Group 2 for all sub-themes. Both groups recorded the highest values for the sub-theme 'Sights/Interactions' with an average of 5.25 entries and 5.75 entries for Group 2 and Group 1, respectively. As expected, the 'Sound' sub-theme had the lowest averages for both groups, with Group 1 recording an average of just 0.75, while Group 2 recorded zero entries.

However, it is not only the quantity of data but also the quality of that data which suggests greater cognitive awareness during wayfinding. Group 2 participants recorded more generic statements, such as "shops on Blackett Street shut" or "busker"; whereas comments from Group 1 participants included relatively detailed information, such as "guy with drums [but] not playing". Examples of this were recorded by Participant B, who observed "Xmas gnomes in doorways", "missing silver discs", and "yellow umbrellas".

Surprisingly, Participant H in Group 2 displayed a relatively higher environmental awareness during their wayfinding attempt, exceeding the group average. This could be due to the way their level of engagement with the technological tool (i.e., using a mobile phone to send messages for only "3-4 minutes" of the journey), as noted in the post-wayfinding survey. This infrequent level of an engagement with the technological tool leads to an intermittent distraction from the environment, and therefore might still allow for the traveller the opportunity to absorb increased environmental information during navigation.

	THEME CATEGORIES	GROUP 1 AVERAGE	GROUP 2 AVERAGE
'STATIC ELEMENT' THEMES	DISTRICT / AREAS	2.25	0.25
	STREETS / STREET NAMES	3	2
	BUILDINGS / STRUCTURES	4.5	2.75
	SHOPS / RESTAURANTS	9.5	5.25
	LANDMARKS	1.25	1
'JOURNEY SPECIFIC' THEMES	ENVIRONMENTAL PROPERTIES	2.25	0.75
	SIGHTS / INTERACTIONS	5.75	5.25
	EXPERIENCE / FEELING	2	0.75
	SOUND	0.75	0

Table 4: Thematic Analysis as quantified for both groups.

At the group level, there seems to be a significant difference in the prioritisation of the type of information recorded (Table 4). While the average frequency of 'static element' theme is higher compared to 'journey specific' theme across groups, Group 2 participants seem to focus more on the static elements of their journey, such as shops/restaurants and buildings/structures (with a very low average score (1.5) for 'journey specific' theme). On the other hand, the average score of 'journey specific' theme is considerably higher for Group 1 (10.5).

Since all participants were somewhat familiar with the case study area, the familiarity variable was controlled for. This is evident in the cognitive maps which included points of reference which have not been utilised within the wayfinding attempt. A prime example of this is Northumberland Street which is referenced on all but one cognitive map, meanwhile only 50% of the actual routes covered this street. Other examples include key landmarks, such as Grey's Monument (referenced 7 out of 8), or more subject-specific static elements, such as favourite shops. It is therefore clear that the remaining elements of the participants' 'image' is orientated about this precise network.

5 CONCLUSIONS

This study asked 8 participants, randomly assigned into 2 groups with access to technological tools being the differentiating factor, to navigate through the city-centre of Newcastle upon Tyne, UK, between a predefined origin and destination and to conduct a post-activity survey and cognitive mapping activity upon completion of the task. Travelled routes were then compared against the 'predicted route' identified based on space syntax Angular Integration (AIN) and Normalised Choice (NACH) measures to reveal differences in route choice behaviour among both groups. Surveys and cognitive maps were also analysed to reveal the differences in spatial knowledge acquisition between the two groups of navigators.

While it could be argued that all the participants recorded successful wayfinding attempts due to them all reaching the final destination unscathed (Timpf & Sabine, 2002), the findings demonstrated that travellers who did not engage with any technological tools, such as smartphones, displayed greater awareness of their environment during navigation. This was evidenced in the higher number and increased detail of environmental cues recorded in post-wayfinding surveys and cognitive mapping, which provided essential information in relation to this trend. This appears to align itself with the definition of a successful '*explore'* (Allen, 2004).

However, this heightened environmental awareness did not translate into increased selection of segments with high connectivity values during wayfinding. Analysis of individual cognitive maps identified that this was not due to a lack of awareness of these spatially prominent segments within the system as these segments were often still recorded. The surveys and cognitive maps suggested that these participants observed their surroundings more acutely compared to those with access to technological tools, and consciously avoided these highly connected segments with specific environmental affordances, such as increased pedestrian densities, due to COVID-related safety concerns at the expense of the most direct route. This observation could be due to the current global pandemic which has instilled a sense of fear towards large groups. Hence, it can be argued that environmental affordances are significant mediating factors in shaping route choice behaviour, and depending on the collective and individual circumstances, they might support active travel, as is largely argued within planning and space syntax literature (i.e., well-connected streets draw more pedestrians from their surroundings, which result in safer environments for the pedestrian (Hillier, 2004) (Zakaria & Ujang, 2015) or act as a barrier to walking.

On the contrary, although participants engaging with technological tools during navigation were less aware of their environments, in particular of 'journey specific' cues, such as interactions and experience, they displayed a more effective wayfinding attempt in terms of reducing their cognitive effort by more frequently selecting segments with reduced direction changes. This is evident in the increased % overlap of travelled segments with the 'predicted route' as compared to Group 1 participants but is also reinforced by the shorter average travel time and distance. This could be due to the limited environmental data absorbed and therefore reacted against during navigation, which leads to minimal divergence from the initial planned route.

Moreover, it seems that the way in which the cognitive maps were drawn mimicked, to an extent, the way in which the wayfinding task was conducted. Participants who produced highly detailed cognitive maps also recorded greater quantities of information in the form of environmental cues and were therefore likely to deviate from the 'predicted route'. Analysis of individual travelled routes indicated that participants started their journey along a similar initial network that lied along the 'predicted route', which can be argued to be the result of a shared 'environmental image' based on the city's primary structure. This route choice strategy then started to vary among participants as a result of the environmental information acquired during wayfinding, which in turn altered the ‘environmental image’ and hence led to a less effective wayfinding in terms of cognitive loading (i.e., deviating from the most connected segments to compensate for specific affordance). For example, Group 2 recorded a more precise network of identifiable static elements which allowed them to complete the task in the most effective manner, following the most connected route more closely. On the other hand, the average score of ‘journey specific’ theme was higher for Group 1, which points to a greater appreciation of the unique environmental elements observed during the wayfinding task. This process of environmental engagement can be argued to lead to an individual process of systematically identifying the network elements by which the traveller’s image of the city is formed.

Overall, this study confirms that wayfinding is a complex task that is shaped by multiple factors, including cognitive effort and environmental affordances (Bailenson, et al., 2000) (Crowe, et al., 2000) (Gibson, 1979), Hence, it is not straightforward to determine what constitutes a ‘successful wayfinding’. What can be postulated based on the findings discussed here is that it is the purpose of the wayfinding task which ultimately determines what is considered as most successful. For example, if the aim is to reach a destination in minimal time and with least amount of cognitive burden, then it could be suggested that using technological tools during navigation would be advantageous as it is likely to lead the traveller to follow a more direct route. Conversely, if there is less demand to follow the spatially most prominent route, then it could be argued that opting against using technological tools during navigation will result in far richer wayfinding experience with heightened environmental awareness.

An important limitation of this study is the limited sample size. Due to recent COVID-19 lockdown restrictions when the study was conducted, further invited participants were unable to complete the tasks. It also means that all participants had some degree of familiarity with the case study environment. Increasing the quantity and diversity of participants with different levels of familiarity with the area could allow for further investigations into other wayfinding-related factors, such as the effect of having a good memory upon the results. Future research should be extended to explore the role of 'good memory' (i.e., when participants only vaguely know where to go, or need to look at a map at the start of their journey) in route choice behaviour. These limitations mean that the findings are not generalisable to the wider population.

However, the qualitative data obtained from the post-activity surveys and cognitive maps still offers valuable insight within the current field. More advanced methods, such as GPS tracking, could be employed to increase sample size without additional time and effort in data collection. This approach would also overcome issues such as data inaccuracy. In addition, this study was conducted during a global pandemic in an urban city-centre, which could influence participants’ travel decisions (i.e., avoiding crowded street segments due to perceiving increased pedestrian footfall as a negative affordance due to health and safety). Further research should be conducted during post-pandemic conditions and in various settings (e.g., in a suburban setting) nationally and internationally to test the validity of these findings and observations across different cultures.

Nevertheless, this study contributes towards wayfinding knowledgebase in the built environment by expanding our understanding on how the continually growing presence of technological tools within our modern society is influencing wayfinding behaviour and spatial cognition. Further elaboration of this research might lead to an in-depth understanding of spatial knowledge acquisition during navigation, which, in return, could provide significant input to successful post-pandemic planning and re-vitalisation of city-centres.

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