Motion features of digital path tracing in urban map navigation

Alice Vialard[1] [0000-0002-6719-7122] and Rutger Zietsma[2]

[1] Northumbria University, 2 Ellison Pl, Newcastle upon Tyne NE1 8ST
[2] Manus Neurodynamica Ltd, 12 Alva Street, EH2 4QG, Edinburgh

Abstract. This study examines the physical features involved in navigating maps representing urban areas and more specifically when making decision to reach a defined location. A subject is presented a series of maps and is asked to draw the shortest path between selected locations and the centre of the map in order to assess the level of accessibility and intelligibility of urban environments. It is designed to better understand how people select routes and how decision-making may be understood through analysing the drawing process. The process is quantifying through digitally recorded fine motor skill measurements while drawing a path between two points following the street network. Recorded velocity, completion time and measures of drawing accuracy are used to assess the complexity of navigation. This pilot-study confirms that the presence of intersections along the path impacts the speed of tracing. It also establishes that the mode of representation of urban environments has also an impact on the speed of tracing as well.

Keywords: Path tracing, Map navigation, NeuroMotor pen

1 Background

Usually decisions in travel behaviour concern the choice of destinations and the selection of a path to reach this destination [1]. Determining a path involves multiple steps such as identifying the destination, planning the path, identifying choice points, and making the right decision at the choice point [2]. Many studies have highlighted the role of distance, presence of intersections and changes of direction [3] on decision-making. This study focuses on decision points that occur at intersections while tracing a path to a given destination. It builds on previous research on navigation of urban environments that looked at how people make decision using fixation time [4] [5]. This study explores similar environments but focuses on the physical effort involved in selecting a path by tracing over a map. It records hand motion as subjects draw a path between two fixed points with a special pen that is designed to quantify fine motor skill. It includes x- and y-coordinates, velocity and levels of temporal and spatial accuracy [6].

The pen velocity can provide insight on how decisions are made, recording potential hesitations at intersection as one slows down, pauses or accelerates. These measures can help assessing different levels of intelligibility that are established based on the ease of navigation to the centre, which reflect a level of accessibility. In many studies, the speed of decision-making is measured by the time taken to complete a task [7][8].

This small-scale study also looks at parameters that can influence completion time, which are not linked to the intelligibility of urban environments but to the mode of representation. This concerns the representation of the public space in urban areas drawn as a set of street segments, or as the leftover space between urban blocks.

2 Path tracing

2.1 Setting

Neuromotor pen system. The experiment entails to look at a series of maps on a digital support (locked down tablet pc) with an app to provide a convenient user interface and the use of a digital pen to trace the shortest path between two points. The NeuroMotor pen is a biomedical device designed primarily to detect early signs of movement disorders in a non-invasive way. This technology provides recording of minute changes in motion patterns (such as pressure, velocity and three-dimensional orientation) when performing a task [9]. This provides a convenient platform for complex motor skill data acquisition.

Map representation. The maps represent urban areas within a half-mile diameter (13.7cm-diameter map on display). They are circular to provide consistent distances throughout the sample between the peripheral points and the centre. Two types of maps are presented for the same area: urban block and street segment (see Fig. 1). In the urban block map, the public space is represented as the leftover space between urban blocks. In the street segment map, the public space is made of a set of segments representing the centerline of that open space. In the block map, the average width of the white space appears on average 3.8 mm on the display, while the line of the segment map are only 0.5 mm thick.

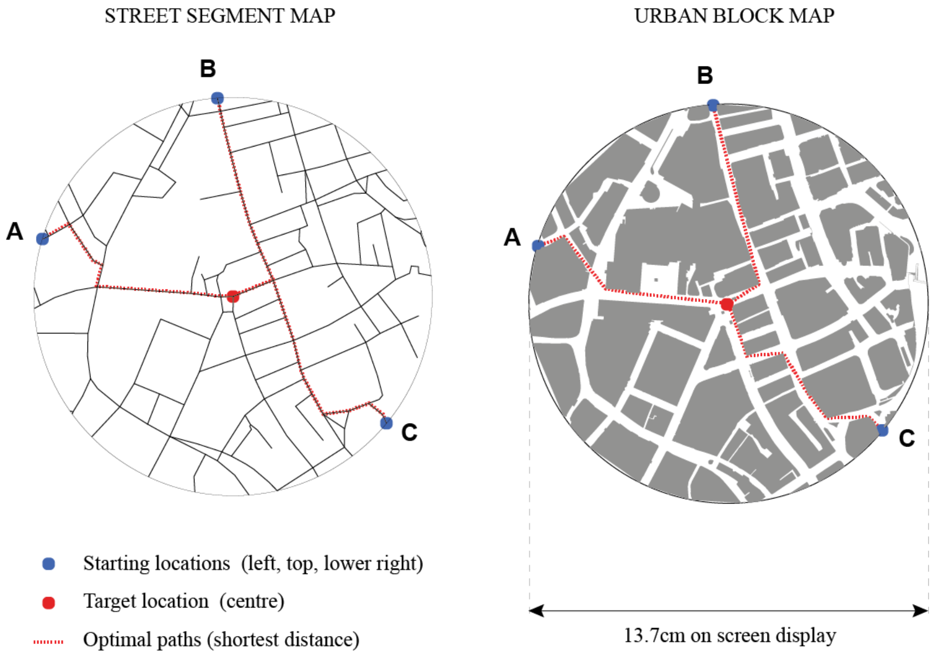

Fig. 1. Two modes of representations for the same urban area: on the right, streets defined by the boundary of the urban blocks; on the left, streets represented by segments located on their centerlines. Optimal paths are paths with the shortest distance between the starting and target locations.

Task. The task looks at the accessibility of the centre of a neighbourhood, here the city centre of Newcastle upon Tyne, from three equidistant starting locations. The participant is asked to draw the shortest path from the points located at the periphery (A, B and C) to the target location located in the centre. No time constraint.is applied. This pilot-study uses two full recording from a participant unfamiliar with the environment, and one full recording from another familiar with the environment. Each set of recording encompasses 18 path tracing from six maps (three urban block and three street segment maps) which represent the same area but rotated twice. The first rotation is moving the starting location C to position A, then C to position B. The rotation is to include potential effect of the directionality of drawing [10] [11].

Table 1. Characteristics of the optimal paths by types of map (block and street) and types of path (A,B,C): path length, number of intersections, cumulative directional changes, the number of changes of direction and the number of turns.

Map type	Path type	Path length	Intersec-tions	Cumulative directional change	Changes of direction (>20°)	Turns (>40°)
Street Segment	A	680.2	7	328	5	3
	B	657.0	9	102	1	1
	C	732.3	11	283	4	3
Urban Blocks	A	612.2	6	116	2	1
	B	619.2	8	72	1	1
	C	647.0	10	247	4	4

The physical characteristics of the optimal paths for each starting location (Table 1) are associated with levels of complexity. While paths A and B can be differentiated by their level of straightness and number of intersections, they remain fairly similar. By contrast, path C is considered as potentially the most complex to navigate as it longer, has high number of intersections and turns, and is the least straight. Furthermore, the characteristics of the optimal path for each point vary according to the type of representation. The block representations tend to have a lower cumulative directional change and tend to be shorter (by approximately 10%.) than the equivalent path in the segment representations.

2.2 Measures

Position of the path tracing is recorded by continuous sampling (200 Hz). Each position is associated to a set of coordinates (x and y), a timestamp, if the pen is touching (1) or hovering over the map (0). The primary data are used to compute distance, time and directional change between two successive locations. From these measures, velocity and acceleration at each position are inferred. For each path, aggregated measures are generated: the length of the path (total distance), the total time for completion of the path, its straightness (cumulative directional changes), mean veloc-ity and mean acceleration. Finally, the accuracy of the tracing is defined as the mean deviation length from each location on the path to the closest segment on the map (see Fig. 2).

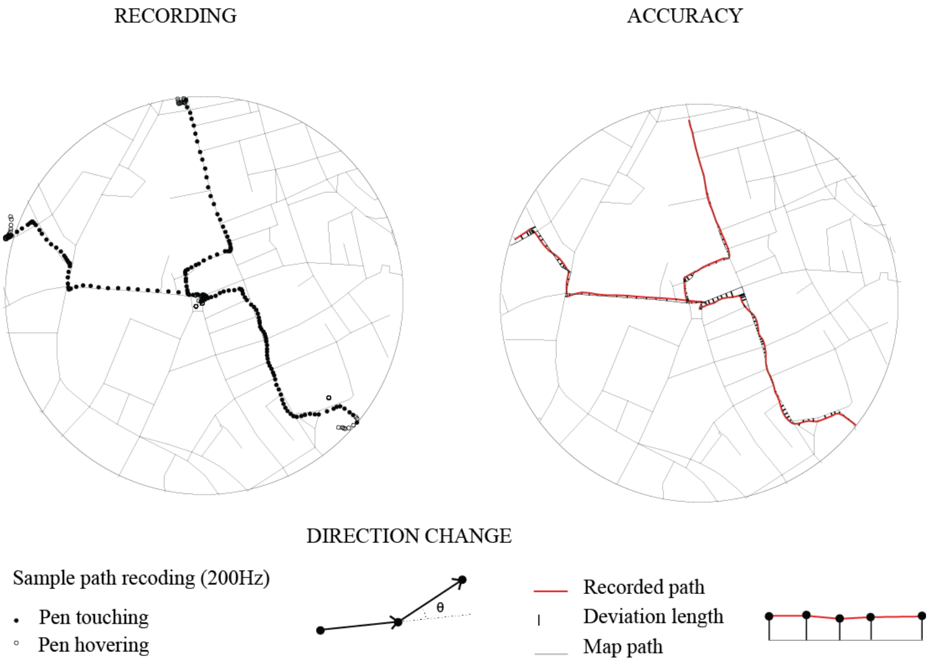

Fig. 2. Example of recording for a path showing when pen is touching or not. From this recording, directional change, deviation length can be computed.

3 Preliminary results

3.1 Modes of representation

The bars (Fig. 3) show the mean values for path length and completion time per type of map (blocks and segments) and per path type (A, B, C). The mean recorded path lengths per map type confirm the characteristics found in the optimal paths, which are longer for segment representation. Seemingly contradictory, the completion time is lower for the segment maps although the paths are longer than for the block maps. However, when comparing them within each path type, in both representations, the longest path with the highest value for cumulative directional changes (Path C) retains the higher completion time. The recordings for each path A, B and C confirm that systematically pen velocity is lower for the urban block representations. These results suggest that following a line with a pen might be physically easier than following a less visually defined trajectory.

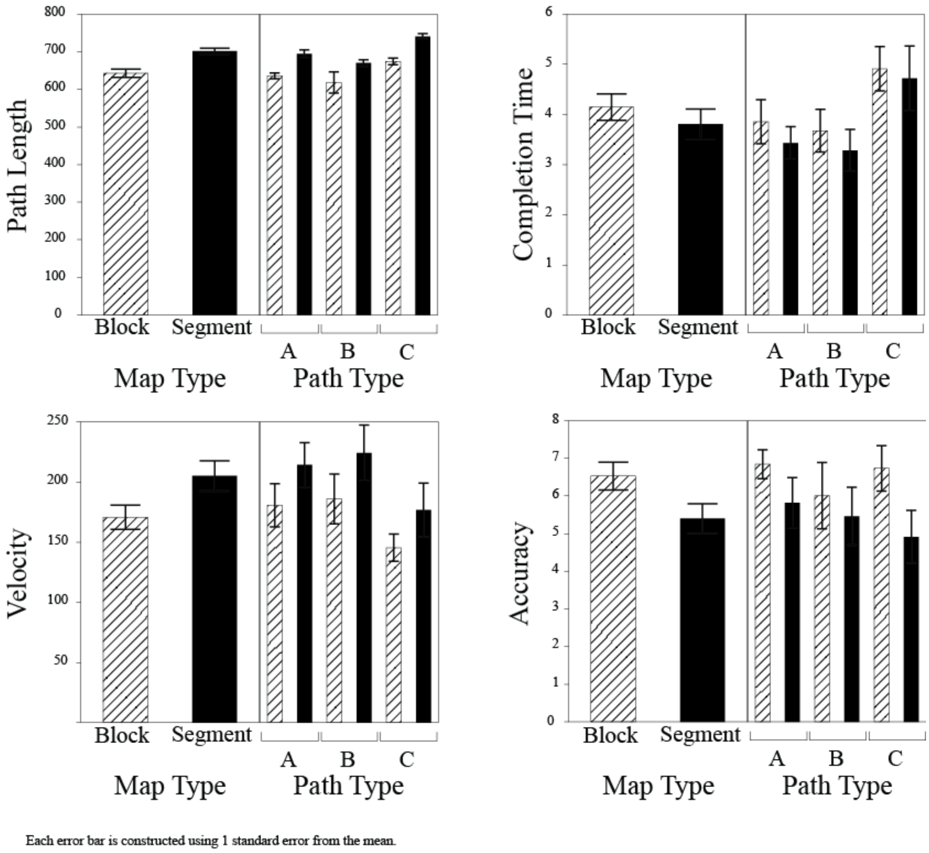

Fig. 3. The bars show mean values for Path length, Completion Time, Velocity and Accuracy by Map type and by Path type. Standard error bar is provided for each mean. High values in Accuracy mean higher level of deviation from the optimal path.

Accuracy. Accuracy is computed based on the deviation length between the recorded path and its equivalent on the map. The recorded path does not necessarily correspond to the optimal path. The graph (see Fig. 3) shows variations according to the type of representation. It is expected that the tradeoff velocity/accuracy often observed in similar tasks [12] will apply: as the pen moves slower, the trace is more accurate. However, the level of accuracy observed is lower for the block representation when comparing within path types. The lack of correlation between velocity and accuracy can be explained by the absence of timing-constraints [13]. It has been shown that the speed-accuracy tradeoff is more likely to happen when a time constraint is applied.

Hovering. The recording of the task highlights differences of pen interaction with the tablet: when the pen is touching (1) which corresponds to the tracing period and when it is not touching (0), the non-tracing period. During the non-tracing period, a further distinction can be made between recordings of position with null velocity, and recordings of position with movement characterizing hovering (See Fig. 4**).**

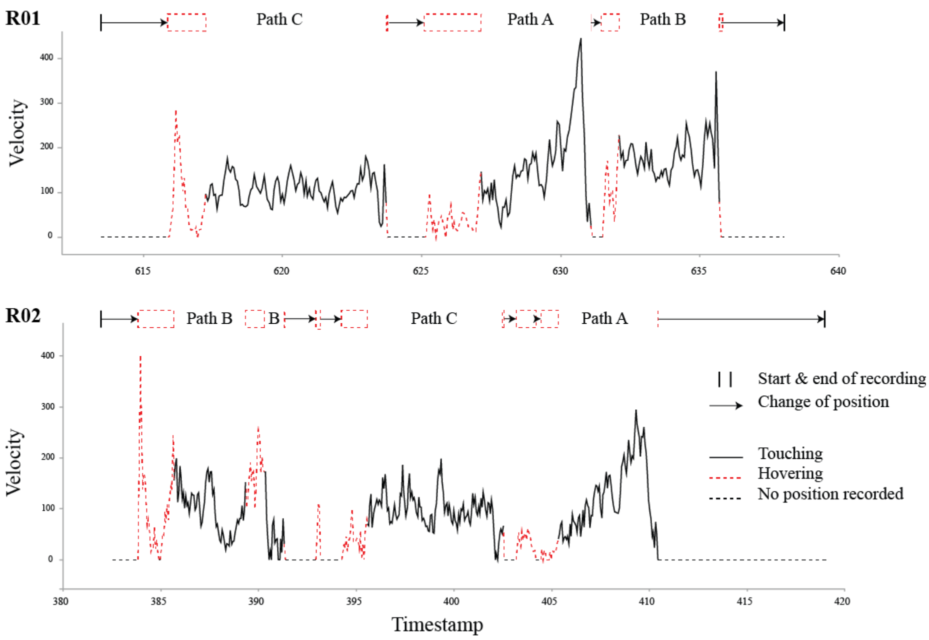

Fig. 4. Plots of velocity for two recording (R01 and R02) highlighting the differences between touching, hovering and no recording. The upper part of the diagram illustrates the sequence of each period.

Hovering periods highlight phases that show a degree of engagement with the task. They are usually recorded at the beginning and the end of the tracing, but also when an error occurs and the participant needs to either change the route and backtrack, or pause (lower recording in Fig. 4). The systematic presence of hovering periods with an increased cognitive load, i.e. when the task gets more complex, suggests that these play a role in the decision-making process. More work should be done to distinguish the time used by the participants to look at the map in order to plan their trajectories versus the time to move from the target point to the next starting point.

3.2 Intelligibility of the environment

Intelligibility of the environment can be challenged by the angularity of the route [14][15] but also what is perceived as turns or changes of directions depending on the directionality of the representation [16]. The presence of intersections along a route adds choice and decision points that can also impact completion time.

Change of direction. Completion time is highly and significantly correlated to the cumulative sum of angles when changing directions along the path (R^2= 0.74, n=51, p<.0001*) (Fig. 5). The straighter the path the faster the completion of the task. Interestingly the length of the path has a less significant and lower correlation with completion time (R^2= 0.10, n=51, p=0.0228*).

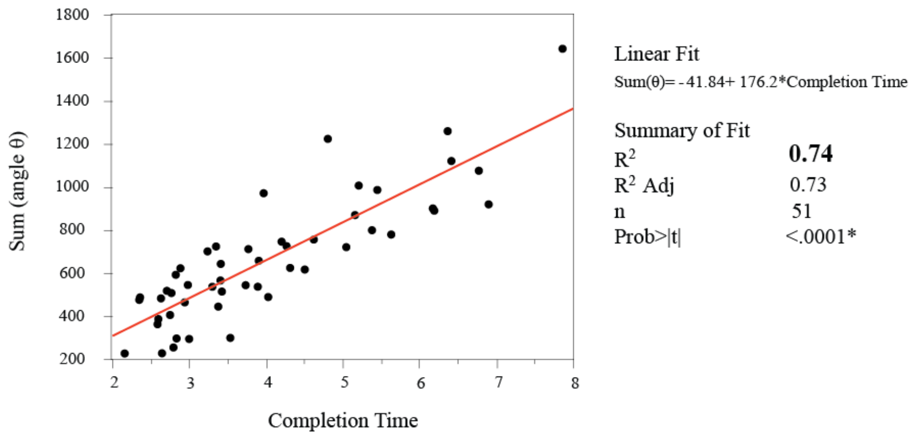

Fig. 5. Correlation between Completion Time and Cumulative changes of direction.

Intersections. Another parameter that may influence the speed of the tracing is the number of intersections, or decision points, that the participant encounters along the path. Fig. 6 illustrates the differences in the recording of pen positions along similar distance and straightness but in which the number of choices varies. Results show that the number of intersections lowers the completion time (see Table 2).

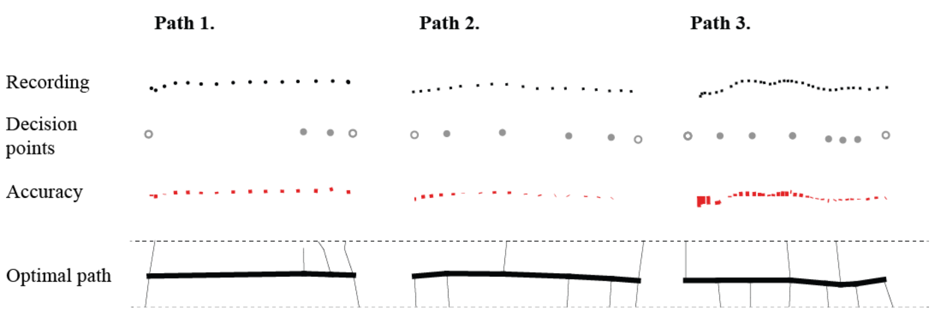

Fig. 6. Sections of recorded paths selected for their similar length and straightness.

Table 2. Values of Completion time, Velocity, and Accuracy according to number of decisions points for 3 recording of the path section 1,2 and 3.

Path	Recorded positions	Decision points	Completion Time	Velocity	Directionality		Accuracy
1	25	2	1.48	**234.14**	L	→	2.91
2	26	4	1.56	218.45	UL	↓	6.88
3	47	6	2.81	86.82	LR	↑	4.23
1	16	2	0.96	**383.91**	UR	↙	5.11
2	26	4	1.26	266.11	LR	↖	3.82
3	34	6	2.03	175.81	UL	↘	5.12
1	24	2	1.44	**246.30**	LR	↖	5.39
2	24	4	1.51	226.14	LL	↗	3.84
3	47	6	2.81	125.88	UR	↙	4.45

Using five different recording of the same paths 1, 2 and 3, a linear regression analysis shows that the number of intersections is also significantly correlated to the mean velocity of the pen (R^2= 0.39, n=15, p=0.0170*). It highlights the relationships that exist between fine motor skill as measured by the pen velocity and decision making with the presence of intersections.

4 Discussion

These preliminary results highlight the presence of different factors involved in our understanding of the decision process while navigating maps of urban environments. They show that while some factors may be associated with the characteristics of the environment, other characteristics depend on the type of representations of the environment.

Tracing versus drawing. One of suggestions is that the modes of representations associate with two types of task, or at least can be perceived as two distinct tasks: tracing and drawing. Although not providing a single choice of path, the street segment representation provides a visible template of the potential optimal path. The task is then mainly associated with tracing over the line. In the urban block map, the line is replaced by an area with less defined boundaries in which the optimal path is not physically defined or visible. The task then involves to draw rather than to trace over the optimal path. Such differentiation might explain the differences in level of accuracy. Studies [17] have shown that tracing can be associated with higher need for spatial accuracy of the pen to match the template while drawing seems to require less positional accuracy.

Hovering periods. These recorded periods when the subject starts to engage with the tracing task can be associated with decision planning or motor preparation before the execution of the path. More work is required to understand the role in the decision-making process. One of the hypothesis is that the non-tracing periods are representative of the eye-hand interaction. They can correspond to the time that the hand takes to reach the target determined by the eye, the gaze locking phase as well as the period where the gaze explore possible alternatives before engaging in the tracing task, the predictive hand processing [18].

The authors have demonstrated that fine motor skill measurements during map navigation enable shedding light on decision making in the planning and execution of movement. The NeuroMotorPen platform technology is proving to be a convenient tool for studying map navigation more widely. It may be used to derive measures that will help to determine which types of map are easiest to navigate, based on for example drawing velocity and how this varies as a function of the complexity of the map, due to multiple angular diversion and the number of intersections presented.

Future work. Ease of navigation may be also determined in specific user groups, such as people with impaired functions or disabilities. This may lead to insights into how maps may be adjusted to accommodate to those user. For this purpose, new or amended maps can easily be uploaded and scaled on the NMP platform. In addition to recording the x,y-excursions of the pen nib and derivatives that were used in the present study, the NMP platform also records complex motor skill measures from the pen movements in three-dimensions. A set of algorithms derives digital biomarkers in an automated fashion to detect movement abnormalities. Since map navigation tasks involve complex processing of information for the planning and execution of motion, the tasks are suitable for assessment of both cognitive functioning and fine motor skill. In the next phase of research, we intend to design map navigation tasks that will be administered in a controlled fashion with varying degrees of complexity and test the validity as a method for assessment of cognition.

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