Do Vibrotactile Patterns on both Hands Improve Guided Navigation with a Walker?

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Abstract. Current assistive technologies for navigation guidance using non-visual feedback often rely on audiovisual cues only. Haptic cues can also provide rich information while leaving the auditory sensory channel unencumbered. By enhancing the sensory information available for guidance, haptics has the potential to improve the adoption of guiding technologies by people with, e.g., visual impairments. This paper evaluates the capacity of tactile patterns delivered by haptic handles to guide users walking with a walker while they are asked to follow a predefined path. We conducted a user study on 18 participants who used two haptic handles mounted on a walker in actual walking condition. We implemented three types of vibrotactile patterns for guidance: uni-manual (one handle), bi-manual (two handles), and dual (combining one-handle and two-handles patterns) were used depending on the direction. We also compared vibration and tapping stimulation modes to test for their potential influence on the guiding strategy and the user's preference. Results showed no significant effect of the strategy or the stimulation mode on the accuracy of following the target path. However, they showed that bi-manual conditions presented a higher satisfaction rate, gave a sensation of being mentally less demanding to users, improved the confidence rate in succeeding the task, and increased the navigation speed.

Keywords: Vibrotactile feedback · Navigation assistance · Walking · Path following · Haptic handle

1 Introduction

In the realm of navigation assistance, today we encounter a large number of challenges, particularly when considering the diverse needs of the different user groups. While vehicular navigation systems have advanced notably through turn by turn systems, offering sufficiently efficient guidance for these applications, these tools are not so well suited for pedestrians, who need significantly more detailed information [11]. The limitations of today's tools become even more apparent when we consider the accessibility aspect and the specific needs of,

e.g. people with visual impairments. For example, current navigation technologies using non-visual feedback often focus on providing auditory-based navigation, ending up overloading the auditory sense. However, the auditory sense is paramount to acknowledge the environment, move safely, a socially interact with others, especially if other senses are impaired. This limitation is further exacerbated for those users experiencing deafblindness, a condition where both visual and auditory senses are impaired, making traditional navigation systems largely inaccessible. Indeed, nowadays most guidance is provided through visual, auditory, or audiovisual stimuli, which is limiting in many situations [19,2,3].

In this perspective, many works have focused on studying the potential of haptics for navigation assistance, as an alternative to vision and audition. Kappers et al. review of hand-held haptics devices for navigation assistance [11] suggests that vibrotactile cues are an interesting and viable way of conveying directional information. While the use of vibrations is straightforward and widespread, receiving these cues during long periods of time can potentially cause tiredness and create tactile noises [24,7]. In that respect, apart from vibrotactile devices, we can see various types of haptic stimuli emerge, using shape-changing [22,21], force [6], pseudo-force [1], and skin-stretch [5,4,13]. On addressing mobility issues encountered by the elderly, some have focused on the development of on-walker embedded assistance. While a part of those works target rehabilitation of gait mobility [20], using for example rhythmic haptic cues after a stroke [9], others aim at better navigation assistance for people suffering from combined sensory and mobility deficiencies [18,26,10]. In this last case, research that involves haptic feedback mainly focus on active guidance by physically pulling the user towards a direction [18,26].

In this paper, we present an experiment investigating the performance of two haptic handles embedded on a walker in delivering navigation information. The handles use the Apparent Haptic Motion (AHM) illusion to deliver rich directional indications to users asked to follow a predefined path. We create and compare three navigation strategies using one or two handles with different tactile patterns [17] and we compare two different modes of stimulation: vibrations and tapping sensations. The study aimed to identify the most effective and intuitive tactile patterns and thus the preferred navigation strategy, as well as to evaluate potential difference in effectiveness and user experience between the tapping and vibrotactile stimulations during an actual navigation task. As the handles are designed to be adaptable to multiple mobility aids, e.g., walkers, wheelchairs, precanes, white canes, these results might be readily applicable to a much broader range of situations and systems.

2 Experimental Device

We developed a haptic handle equipped with five electromagnetic actuators, as depicted in Fig. 1. Inspired by our earlier work [16], this version of the device incorporates significant improvements, such as an enhanced actuator design and positioning. The device has also undergone miniaturisation for seamless integra-

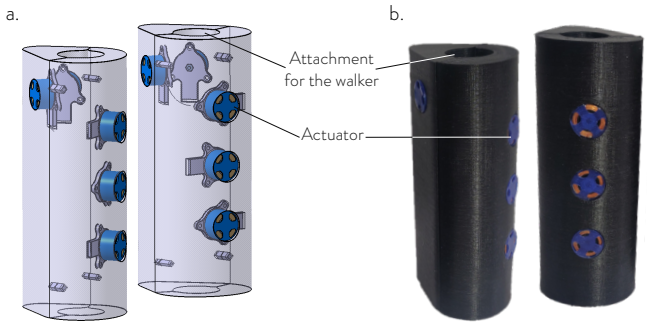

Fig. 1. Right and left haptic handles designed for providing directional tactile sensations. a) Computer-Aided Design (CAD) of the 3D-printed handle, made from flexible TPU material, featuring alcoves to house the actuators in a "T" - shape configuration. This design naturally stimulates the thumb, the second metacarpal bone of the palm, and the index finger. b) Image of the two symmetrically designed handles [17].

tion onto a walker and, in the future, other mobility aids. The handle, made through 3D printing using TPU soft material (Filaflex 82 A, 0.8 mm thickness), has a cylindrical shape designed for comfortable single-handed grip. Actuators are arranged in a "T"-configuration across the handle to stimulate the metacarpal bones of the palm (three motors), thumb (one motor), and index finger (one motor). This handle is designed to replace the default handles of a standard walker (ErgoClick 4-wheels walker), shown in Fig. 2. The same handles were used in [17] for a preliminary study aiming to evaluate the device performance in a static position before having people actually walking around with the device.

The actuators are custom-designed electromagnetic motors, drawing inspiration from the Hapticomm device [8] and previous studies on the Apparent Haptic Motion (AHM) illusion [15,14,16]. They are capable of conveying both vibratory and tapping sensations, referred to as "taps". The actuators are controlled by M5 Stack controllers and powered with a power bank (capacity: 10 Ah/37 Wh, Output: 6-9 V DC, max 2 A), enabling more than four hours of use. A significant effort has been made for miniaturisation and portability, as it is a crucial aspect for the implementation in a study close to real-life condition and its transition towards an everyday use.

3 User Study

Our objective is to evaluate the effectiveness of providing rich and precise navigation assistance through the Apparent Haptic Motion (AHM) paradigm delivered with our custom hand-held interfaces. More precisely, our focus is to compare the accuracy rates achieved with different tactile patterns using one or both hands/handles to identify the most intuitive ones for the walker users in navigation tasks. To do so, we carried out a human participants study aiming to test our devices and strategies in the context of following unknown trajecto-

ries through tactile instructions in actual walking modalities. The study focus on three key factors to be tested: (i) stimulation *Modes*: standard vibrations or discrete "tapping" sensations; (ii) pattern *Strategies*: Bi-manual (using both handles for all directional instructions), Dual (using either one or two handles depending on the instruction), and Uni-manual (only using the handle on the dominant hand side) with patterns distributed around or along the handles; and (iii) complexity of the *Path* to follow. The study received approval from Inria's ethics committee (COERLE, 2021-39).

3.1 Experimental Setup and Methods

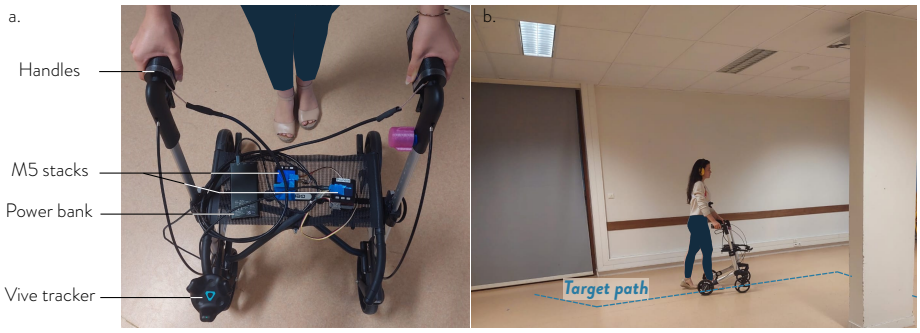

Fig. 2. a) Experimental setup: The handles are mounted on the walker. Signals are amplified and sent to the handles by the M5 Stacks controllers connected via WiFi. The motors are powered through the M5 Stacks cabled to a power bank. b) Navigation: The participant is guided by the tactile patterns along a target virtual path (not visible by the user, dashed blue line in the Figure).

Experimental setup. The experimental setup featured a standard walker equipped with two haptic handles described in Sec. 2, positioned 48 cm apart with adjustable height for user comfort. Participants, wearing noise-cancelling headphones, stood behind the walker, which housed the handle controlled by the electronic setup. The participants navigated in a 8×8 m room in which their position and orientation were tracked using a Vive tracking system, with base stations in the four corners of the room ceiling and a tracker on the walker. The room was empty, with a pillar close to the centre. Participants were asked to follow precisely predefined virtual paths. The position and orientation tracking enabled to evaluate the proper tactile patterns to be given as a directional instruction to the user, according to the experimental condition at hand. No visual information or details about the trajectory to follow were given to the participants, and there were no visual clues except for the starting points marked with tape on the floor. We defined two different starting points diagonally positioned in two of the room's corners. We considered the coordinates of the starting point

as the origin of the spatial referential $(x_{start}; y_{start}) = (0; 0)$, and the closest corner $(x_{corn}; y_{corn}) = (-1; -1)$. Fig. 3 shows the room dimensions and the *Paths* starting at $(x_{start}; y_{start}) = (0; 0)$. The representation shows the two different starting points in opposite corners. When applying a 180° rotation of the participants trajectories in orange, we obtain consistent representations of both blue and orange *Paths* together with superimposed starting points.

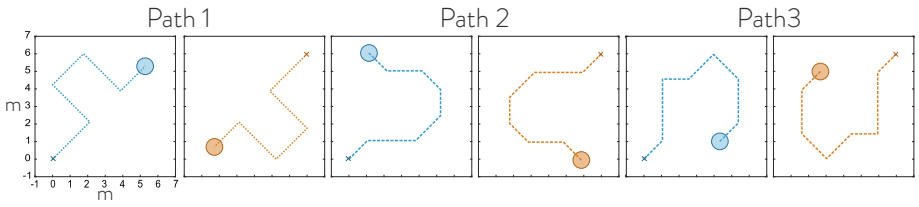

Fig. 3. Paths that participants were tasked to follow. The blue and orange paths are identical but start from two different starting points (× and ×). The coloured discs (● and ●) represent the arrival area, where the target is considered reached.

Tactile patterns. Three strategies to provide directional information were considered: Bi-manual, Dual, and Uni-manual. Figure 4 shows the three navigating strategies and the tactile patterns associated. Building on a previous study on directional indication in a static position [17], we selected tactile patterns utilising the Apparent Haptic Motion (AHM) illusion for navigation cues. These patterns, activated through electromagnetic actuators, conveyed directional information either on a single handle (three actuators) or both handles (six actuators). They are distributed around or along the handles. The coloured arrows in Fig. 4 illustrate the activation patterns for each signal. The gradient of colours, ranging from green to red, depicts the temporal activation of the motors.

Type of haptic stimuli: Two distinct methods of delivering haptic cues—vibrations and "taps"—were achieved by altering the activation *Mode* of the electromagnetic actuators within the handles. The "tap" stimulations comprised a 220 ms square signal, while the vibration stimulation consisted of a 120 Hz sinusoidal signal within a 220 ms square envelope. In both *Modes*, signals were preceded by a negative impulse to pull the magnets down in the coil before pushing them out. The Stimuli Onset Asynchrony (SOA), the activation delay between two subsequent actuators, was set at 110 ms (see [16]).

Paths to follow: Participants had to follow virtual *Paths*. We created three of them to vary complexity and prevent participants from learning them. Paths were designed to have multiple turns, between four and six, with at least two right turns and two left turns. We differentiated *Paths* by the angles of their turns. "Path 1" presents only 90° turns, "Path 2" only 45° turns, and "Path 3" both 45° and 90° turns (see Fig. 3).

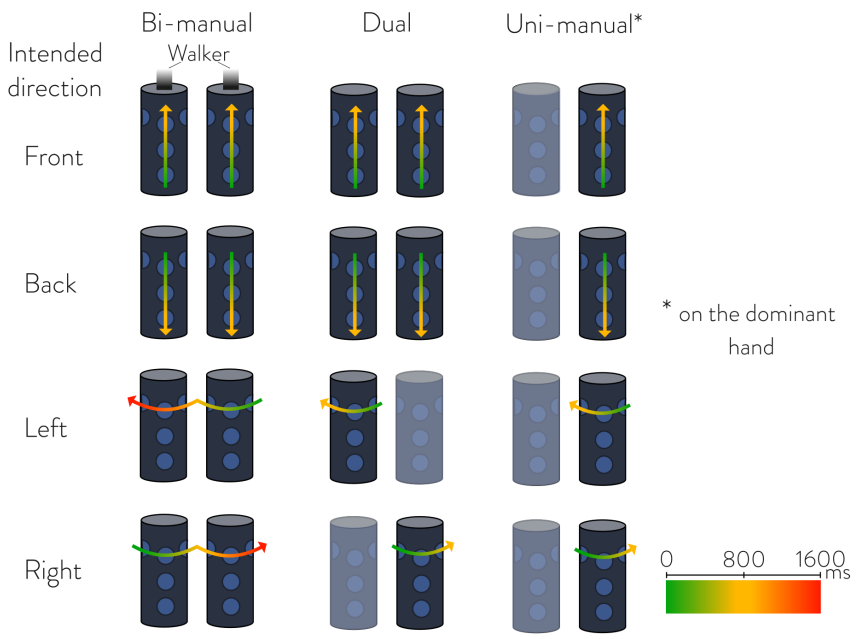

Fig. 4. Directional patterns using the AHM illusion organised in strategies. The coloured arrows depict the pattern of activation, with the colour gradient indicating temporal activation (green to red). Each motor is individually activated, providing tapping or vibratory sensations. For example, when considering the *Front* signal of the *Bi-manual Strategy*, it initiates the progressive activation of the three motors along each handle held by the user's. On the other side, the *Front* signal of the *Uni-manual Strategy* activates the three actuators along the user's dominant side handle. For *Left/Right* indications, the sequential activation stimulates the thumb first, the second metacarpal bone (across the purlicue), and the index finger.

3.2 Experimental Task and Design

Participants were tasked with manoeuvring the walker based on the directional information provided through the handle(s), with no prior knowledge of the trajectory. Signals were generated at a frequency of 0.5 Hz, offering directional information every two seconds. The tracking system monitored the walker position and rotation, which were used to compute and select the directional pattern to be displayed by the handle(s). Users were guided towards a point one meter ahead on the path, similarly to [12]. The tactile patterns were evaluated depending on the angle computed to reach the target position. If the target locates at $\pm 15°$ compared to the orientation of the user, being the $0°$ reference, the instruction given to the users is *Front*, creating a cone of $30°$ of tolerance for *Front* direction, comparable to the parameters used in [25]. The *Back* instruction was sent for a target point located at $\pm 127.5°$ compared to the orientation of the user.

The experiment comprised three blocks (for the three *Strategies*), each featuring two series, one per stimulation *Mode* ("taps" or vibrations). Within each series, participants performed three trials corresponding to the three different target *Paths*. To prevent learning bias, participants alternated between starting points, and the order of presentation of the *Path*, *Mode*, and *Strategy* conditions were counter-balanced. This protocol resulted in 18 navigation trials per participant corresponding to the 18 conditions: 3 *Path*s×2 *Mode*s×3 *Strategies*, with no repetition.

3.3 Participants and Collected Data

Eighteen participants, aged between 21 and 35 ($mean = 25.2$, $sd = 4.4$), including four left-handed people, six women, eleven men, and a participant identifying as non-binary, took part of the experiment. Participants were naive about the study hypotheses and design. The experiment lasted one hour. They signed an informed consent form and completed demographic questionnaires. Then, they got 2 minutes to experience manoeuvring the walker without receiving tactile patterns on the handles. Before each change of *Strategy* and *Mode*, participants tested the patterns while the experimenter indicated what was the given interpretation of each tactile pattern. Throughout the task, we collected the participant position, the walker orientation, and navigation information, as well as their level of agreement on a 7-point Likert scale to various statements, as detailed in Sec. 4. At the end of the experiment, we collected the user's preferred guiding *Strategy* and *Mode*, as well as open comments and general feedback.

4 Results

Fig. 5 shows the data of all eighteen participants' trajectories, categorised according to the *Strategy* and the stimulation *Mode* conditions for the three different target *Path*s. Each graph presents the target *Path* (doted black line) and the eighteen participants courses (coloured lines) for each condition.

4.1 Statistical analysis on trajectory data

For our data analysis we considered the following variables. For the independent variables, we considered the navigation strategies, which lead to different tactile patterns using one or two handles (Uni-manual, Dual, Bi-manual), the stimulation *Mode* ("taps" and vibrations), and target *Path*s (see Fig. 3). For the dependant variables, we considered (i) the Dynamic Time Wrapping (DTW) computed on participants trajectories, (ii) the duration of their courses, and (iii) the total distance covered during each trial.

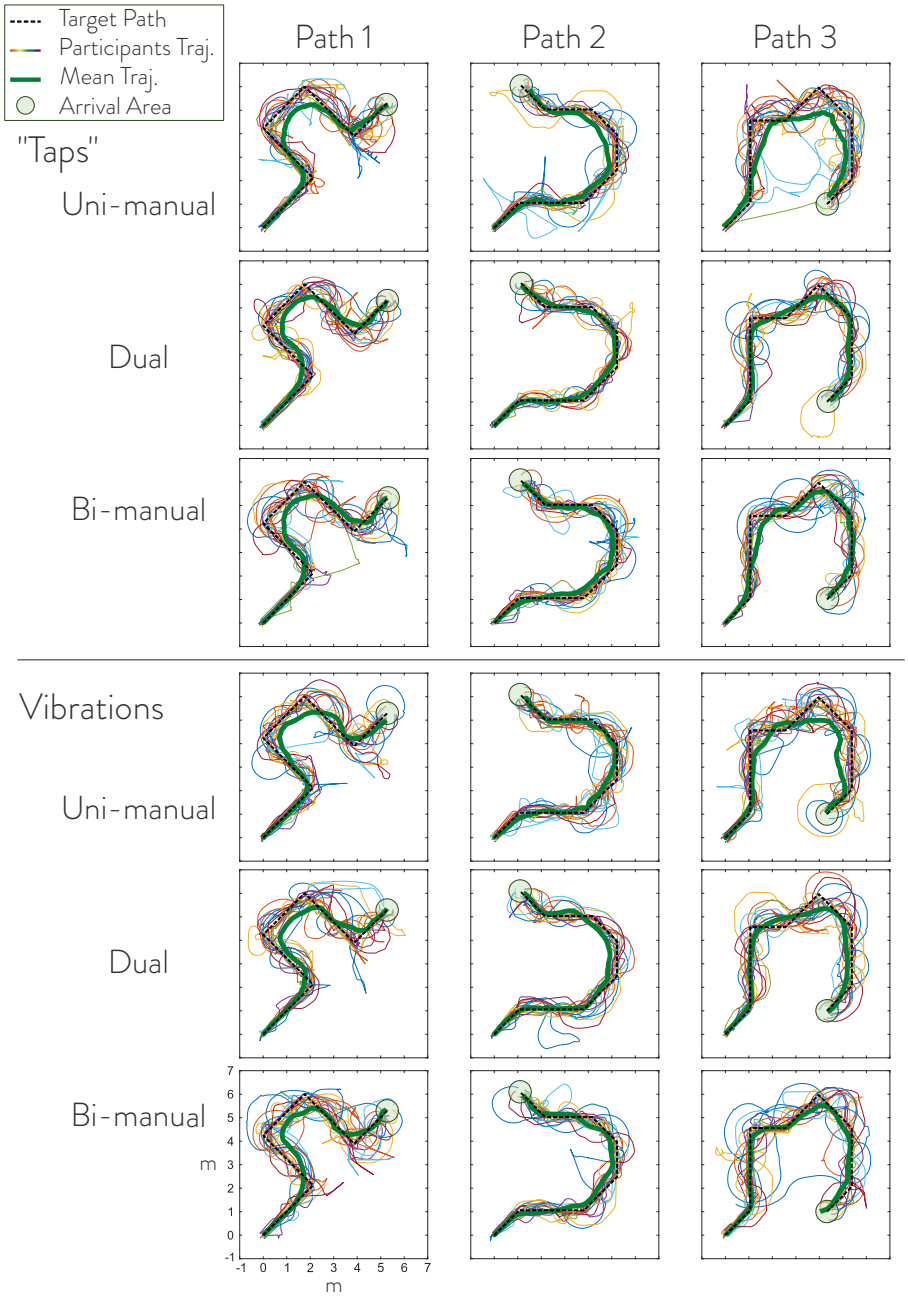

Fig. 5. Collection of all participants trajectories for each condition of guiding: *Strategy*, stimulation *Mode*, and *Path*. The dashed black line represents the target *Path*, the thick green line is the mean trajectory among the 18 participants, and the thin coloured lines are participant trajectories. The light green disc represent a 0.5 m radius area around the arrival point, considered as the arrival area. The axis represent the 2D space of the room, with the origin of the task placed at the same starting location for representation.

Dynamic Time Wrapping (DTW). We computed the Dynamic Time Wrapping distance as a measure of the distance between matching pairs of points in the target *Path* and the participant trajectories. More specifically, the DTW identifies a wrapping *Path* between the target signal and the participant trajectory signal so as to find the closest corresponding point on the target, and create the corresponding pairs of points. We used the package "SimilarityMeasures" on RStudio and the function DTW [23]. As the DTW metrics also depends on the number of points over the signal, we normalised the DTW by the number of points in the participant trajectory. We thus obtained a mean value of distance to the target *Path* along the whole trajectory. Data showed overall: a mean value of distance from the target $D_{mean} = 0.58m$; median $D_{med} = 0.49m$ and standard deviation $D_{std} = 0.38m$ over all participants and conditions. As the data distribution does not follow a normal distribution, we ran a Generalised Linear Mixed Model analysis, considering as independent variables the three navigation *Strategies*, the stimulation *Modes*, and the three different *Paths*. From the Wald Chi-square test performed on the GLMM, none of the three factors has an impact on the distance to the target calculated through the DTW ($p > 0.05$).

Trajectories duration. For the measure of the duration, we looked at the impact of the independent variables *Strategy and Mode*. Because Paths 1, 2 and 3 have different lengths, we separated the data based on the *Path*. Furthermore, as the data did not satisfy the normality requirements to perform an ANOVA, we ran a GLM analysis to investigate the possible effect of the *Strategy* and the *Mode* of stimulation on the time (thus the velocity of participants) and the total distance covered by participants during a trajectory. For the time data, the Wald Chi-square test (*Strategy*, *Mode*) performed on the GLM showed no impact of the *Mode* ($p > 0.05$). However it showed a significant effect of the *Strategy*. For Path 1: $\chi^2(2) = 13.176$, $p = 0.001$; for Path 2: $\chi^2(2) = 11.523$, $p = 0.003$; for Path 3: $\chi^2(2) = 14.618$, $p < 0.001$. The post-hoc Holm test on the *Strategy* showed that Uni-manual *Strategy* significantly increases the reaching time compared to Bi-manual ($p < 0.01$) and to Dual ($p < 0.01$). No significant difference was found between Bi-manual and Dual *Strategy*. Data showed overall: a mean value of time $T_{mean} = \{83; 75; 88\}$ s for *Paths* $\{1; 2; 3\}$ respectively; median $D_{med} = \{74; 63; 74\}$ s and standard deviation $D_{std} = \{34; 36; 41\}$ s over all participants and conditions.

Total covered distance for each trajectory. We look at the total distance of participants' trajectories, separating once again the data based on the studied *Path* number, also analysing the impact of the *Strategy* and *Mode*. From the Wald Chi-square test (Strategy, Mode) performed on the GLM, none of the two factors had an impact on the total distance ($p > 0.05$).

Subjective Evaluation. After each *Path*, *Mode*, and *Strategy*, participants had to evaluate on a 7-point Likert scale how much they agreed with the given statement, 1 being "totally disagree" and 7 "totally agree". The statements are

named according to their order of presentation to the participants, from 1 to 14. Statements for which strategies showed no significant effect are reported in Table 1, with the corresponding median value and the standard deviation. Statements on which strategies had an effect are presented in Table 2, showing the p-values of the corresponding strategy effect. The values of median and standard deviations for these statements are then given in Fig. 6.

Results on a 7-points Likert scale for the three strategies

	Median	Std
S3: The stimulations are pleasant.	6	1.14
S4: The stimulation intensity is appropriate.	5	1.64
S5: The use of the device is effortless.	6	1.76
S7: The task is physically demanding.	1	0.95
S8: I confidently navigated.	6	1.26
S9: The haptic assistance is useful to follow the trajectory.	6	1.13
S10: The haptic assistance is easy to use.	6	1.52
S11: I could use the device without prior instructions.	5	1.57
S12: I learnt how to use the device quickly.	6	1.43
S13: It is fun to use.	6	1.26

Table 1. Median and standard deviation of the 7-point Likert scale evaluation where the Post-Hoc Holm tests results showed no significant effect of the *Strategy* ($p > 0.05$). Data for all 18 participants.

For the statements *S1* to *S7*, the same statements are given for vibrations and "taps". Each data is answered according to the three *Paths* covered in the same *Strategy and Mode* conditions. We performed a GLMM with a Poisson model, where *Strategy* and *Mode* are the 2 independent variables. For each answer the participants did 3 trajectories (Path 1-2-3) in each *Mode* and *Strategy*. The Post-Hoc Holm tests results are reported in Table 1 for non significant results and in Table 2 along with the evaluation results in Fig. 6 for results showing an effect of the *Strategy*. The significant effect are shown using "*". No effect of the *Mode* was found on these statements ($p > 0.05$).

For statements *S8* to *S14*, the question/answers were given after performing all trials for a specific *Strategy*, compiling data for "tap" and vibratory *Mode* or the *Path*. Only the *Strategy* is a independent variable. Answers are still given on a 1-7 Likert scale. This type of data required Krustal-Wallis rank sum test as the data did not comply with normal distribution requirements for ANOVA.

	Strategy comparison		
	Dual - Bi	Uni - Dual	Uni - Bi
S1: I think I succeeded in completing the task.	$p > 0.05$	$p = 0.032^*$	$p = 0.032^*$
S2: The guiding *Strategy* is easy to use.	$p > 0.05$	$p = 0.037^*$	$p = 0.024^*$
S6: The task is mentally demanding.	$p > 0.05$	$p = 0.030^*$	$p > 0.05$
S14: I am satisfied with the navigation *Strategy* (tactile patterns).	$p > 0.05$	$p = 0.042^*$	$p = 0.042^*$

Table 2. Post-Hoc Holm tests results for the subjective evaluation of the stimuli showing a significant effect of the navigation strategy. Data for all 18 participants.

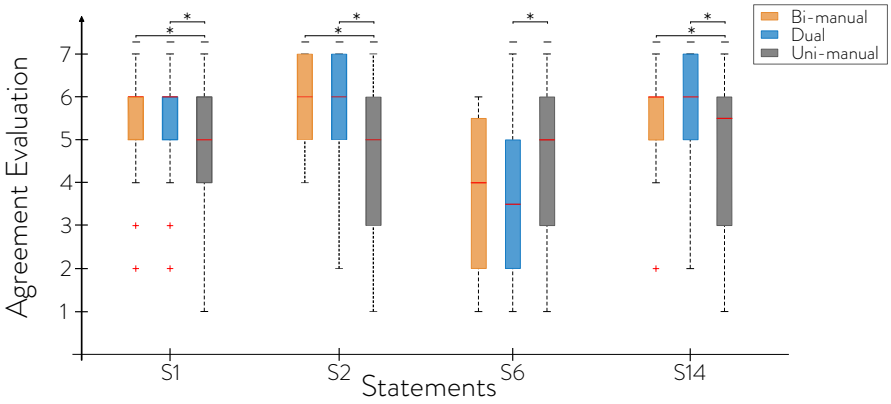

Fig. 6. Participants' evaluation of given statements showing significant effect of the *Strategy*. Answers are given on a 7-point Likert scale. Red markers indicate the median value. The bottom and top edges of the box indicate the 25^{th} and 75^{th} percentiles, respectively. The whiskers extend to the most extreme data points not considering outliers. Outliers are plotted using the +.

5 Discussion

We conducted a user study with eighteen participants, who walked on virtual paths with the sole help of tactile indications provided on custom walker haptic handles. We tested three strategies of tactile patterns, using one or two handles. In this study, various factors were examined concerning navigation strategies using different tactile patterns, stimulation modes ("taps" and vibrations), and target paths. Statistical analyses were conducted on dependent variables such as participant trajectories—to evaluate the distance to the target (using the DTW), course duration—to determine impact on intuitiveness and confidence, total distance—to see if participants would over-walk in certain conditions, and Likert scale evaluations—to assess the user experience and cognitive load. The Dynamic Time Wrapping distance was employed for trajectory analysis, revealing no significant impact of *Strategy, Mode,* or *Path*. The value of the distance to the target found with the DTW ($mean = 0.58\ m$) is promising. Indeed, it suggests that participants should be guided on a path located about 60 cm away from obstacles, which is compatible with most public and outdoor environments, where the device is meant to be used. The same observation was made on the total distance covered during the trajectories. However, trajectory duration was significantly influenced by strategy, with the Uni-manual approach making the participants' courses longer in time, suggesting the Uni-manual strategy affected the confidence of participants. Likert scale evaluations indeed indicated that the Uni-manual strategy negatively affected participants' confidence, as they perceived their success in the task lower, and found the guiding strategy was less easy to use, mentally more demanding and were less satisfied with this strategy. However it is important to notice that their actual displacements were as good with the Uni-manual strategy as with the other two strategies.

6 Conclusion and Perspectives

We conducted an experiment with eighteen participants to evaluate in close to real-life conditions two haptic handles mounted on a walker for performing navigation tasks. Two stimulations modes ("taps" and vibrations) and three navigation strategies (Bi-manual, Uni-manual, and Dual) were tested. For all strategies and modes, the path was adequately followed by participants with no significant difference. However, Uni-manual was never cited as a preferred navigation strategy: nine participant preferred the Dual strategy and nine preferred the Bi-manual. Similarly, for mode preferences, nine participants preferred "taps" and nine of them preferred vibrations. Overall, these findings highlight the importance of strategy in influencing both objective performance metrics and subjective user experiences during navigation tasks. The design of the handles and the results on participants' capacity to follow a *path* with all three *strategies* makes it easy to adapt to different mobility aids, that will be tested in the future, such as the precanes, the power-wheelchair, the cane, for people with single or multiple impairments.

A limitation of this work is the narrow range of ages that we considered for our participants. Moreover, as mentioned for the Uni-manual strategy, training could have an impact on participants performance, and needs further evaluation. It would be indeed relevant to understand and evaluate how long-term use of the device could impact and improve its effectiveness.

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Disclosure of Interests. The authors have no competing interests to declare.

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