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The Effect of Directional Tactile Memory of the Back of the User on Reaction Time and Accuracy

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Abstract: Tactile memory is the cognitive process of storing and recalling information that has been perceived through the sense of touch. Directional tactile memory involves the encoding and retrieval of sensory data associated with a tactile experience, allowing individuals to remember and recognize directional information encoded through the sense of touch. A new method for providing directional tactile feedback, at the back of the user, has been developed to investigate the efficacy of directional tactile memory, its decay over time, and its impact during a concurrent cognitive task. Two experiments were presented. In the first experiment, tactile memory deterioration, with a visual or a tactile cue, was tested with different action-cue latencies (10 s and 20 s). In the second experiment, we considered tactile memory deterioration when there was an increased cognitive load as the participants played Tetris. Forty volunteers participated in the two experiments using purpose-built tactile seats with nine motors controlled by an Arduino. The performance data (error and reaction times) were analyzed statistically, and a NASA task load index (NASA-TLX) questionnaire was administered to measure the subjective workload after each of the two experiments. The findings highlighted that the directional tactile memory of the back can guide individuals to the correct point on the screen and that it can be maintained for at least 20 s. There was no statistically significant difference in the number of errors or reaction time with a visual or tactile action cue. However, being involved in a concurrent cognitive task (playing Tetris) adversely affected the reaction time, the number of errors, and the directional tactile memory, which degraded as the time between the directional cue and the action cue increased. Participants perceived the performance while playing Tetris as significantly more mentally and perceptually demanding, requiring more mental and physical effort and being more frustrating. These trials revealed a new potential for a human–machine interface system, leveraging directional tactile memory, which might be utilized to increase the safety of autonomous vehicles.

Keywords: tactile memory; tactile feedback; tactile feedback; humane machine interaction

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1. Introduction

Tactile feedback refers to the passive sensitivity experienced through touch receptors [1] and tactile memory is the storage and retrieval of information received through the sense of touch [2]. Tactile cues can improve the human–machine interface and help in the execution of tasks, leaving the visual and auditory channels free during the execution of tasks [3]. This approach has been used in many fields, including aerial and terrestrial [4] navigation [5] and teleguidance navigation assistance for visually impaired people [6]. In the current literature, tactile feedback is provided when an action is needed; however, it lacks directional information for the individual to look at the area of interest the individual would look at while performing the task, and the usage of tactile memory encoding the directional information [7–12].

Tactile feedback devices have been created for many parts of the body and applied to the wrists, hands, torso, and feet [10–19]. Each part of the body has a different level of sensitivity to different frequency levels, according to Caldwell et al. [20]. Waist belts have been utilized in studies for tactile feedback, employing frequencies between 50 and 240 Hz [21,22]. The torso, in particular, provides a larger surface area in which it is possible to provide several tactile cues, also allowing the arms and hands to be free for other tasks. In the literature, several authors have utilized tactile feedback in the torso, often embedding the vibrotactile motors in the chair in which the human is seated [23]. However, although the torso can be used to provide directional feedback, the vibration mentioned above leads to nausea [23]. Tactile feedback has been used on the palm, hands, fingertips, and wrists [24–30]. Frequencies above 200 kHz applied to the hands can cause discomfort [24], while the optimal perception is at 25–30 kHz. Recent studies from 2019 to 2021 have extensively investigated tactile seat feedback, employing frequencies ranging from 65 kHz to 300 kHz and utilizing various patterns [25,31–33]. Compared to the other possible locations, the back caused the least discomfort and allowed the highest frequency. Also, if an individual is seated, his/her back is in constant contact with the seat, and the back provides the largest surface area, allowing directional tactile cues to be provided. Therefore, the human back might be one of the best parts of the body that can be used to provide directional tactile cues.

There are many applications where the elements of the environment need to be taken into consideration when performing a task, such as in semi-autonomous vehicles [34], flight control systems [35] and healthcare devices for surgery [36,37]; this is particularly important for for autonomous agriculture machine operators [38]; visually impaired individuals [39–41]; and construction workers [42]. In all these cases, tactile memory could potentially make performing the task more efficient and safe.

Tactile memory has been investigated in the hands [3,14], measuring, for example, recognition accuracy and task performance. Yet, the tactile memory of the human back has never been investigated and could be a means for improving directional awareness as the back has the largest surface area and encoding directional information is possible through the back.

This paper introduces a human–machine interaction system that relies on the directional tactile memory experienced by users on their backs. Although tactile memory has been investigated in the literature [14,43], it has been directed towards the hands and forearms. Additionally, it has not been used to provide directional information. We define *Directional Tactile Feedback* as the physical touch that provides directional information, and *Directional Tactile Memory* as the storage and retrieval of directional information received through the sense of touch, enabling the recall of specific spatial cues provided through tactile feedback. In particular, we examined if the participants could remember the direction provided by the haptic system, in which conditions, and for how long, with two studies.

First, we conducted a study to investigate whether directional tactile memory is more effective when action is prompted by a visual or tactile action cue. Mahrer and Miles [14] showed that when a second instance of tactile feedback is provided to the hands it overwrites the first, but this has scarcely been explored in the back. Thus, we enquired whether the tactile direction and the tactile action prompt on the back interfered with each other, and whether instead, the action prompt would be more effective if provided visually. Following this, we also determined the duration of this memory after a stimulus is presented.

Second, on the strength of the previous results, we ran a follow-up experiment in which we used a distraction task (playing the game Tetris) to increase the mental load exerted on the subjects and assess the extent to which the tactile memory was still effective, while they were immersed in another task.

In the rest of the paper, we review the relevant literature; present the new human–machine interface based on directional tactile memory at the back of the users; and the results of the two studies. Finally, we discuss the theoretical implications of the findings.

1.1. Feedback Setup in Autonomous Vehicles and Construction and Industrial Construction Sites

Lylykangas et al. [44] compared different feedback modalities in a driving simulator showing that visual alerts can sometimes be missed when they are in the peripheral vision region of the driver, making them very dangerous to be used in takeover requests.

Audio feedback has the fastest reaction time in several publications [44–46], but it might be challenging to use to provide an accurate directional alert in several locations [44,45,47].

According to the Wickens multi-resource theory [48] the least loaded modality adds the least amount of workload. Calhoun et al. [47] and Gilson et al. [49] investigated tactile feedback with the NASA task load index (NASA-TLX) questionnaire measure of workload and compared it to audio. They found that tactile feedback adds the least amount of workload. Also, tactile feedback is the least used channel when performing any task compared to visual and audio. However, directional tactile feedback has never been investigated, making directional tactile memory (DTM) a very attractive channel to research.

There are examples in the literature investigating the effect of mental load on the driver's comprehension of tactile feedback. Petermeijer et al. [7] investigated static vibrotactile feedback in a single location and compared it to dynamic vibrotactile, where the vibration point moved on the driver's back towards the direction they should be looking. The experiment was conducted in a baseline session without a mental workload, where the subjects were asked to fill out a questionnaire after receiving the vibration pattern to indicate its direction. Following this, a medium mental demand was added. The tactile feedback warned the subjects to take a right or left lane while driving an automated vehicle. Finally, the subjects were given a tactile directional alert while performing an N-back task and driving the autonomous vehicle. An N-back task is performed by giving the driver numbers from 0 to 9 in random order and the driver is required to repeat the number uttered two digits before the last [7], and is used to impose mental demands. The results showed that reaction times were faster for static vibrotactile alerts, and as the driver's mental workload increased, the correct response percentage decreased.

However, the effect of the directional tactile memory of the back of the driver, while engaged in a highly demanding task, has not been investigated; nor has the effect of different directional tactile setups.

In the construction setting, Yadaf et al. [50] used tactile feedback for construction workers in hard hats and eyeglasses to explore using tactile feedback for seamless communication on construction job sites. The work by Lim et al. [51] is an example of a study providing tactile feedback to the back for ergonomic purposes, in simulated construction tasks like lifting and lowering, shoveling, and tying rebar, to explore the potential of this intervention in teaching workers to minimize excessive trunk flexion exposures. However, even in studies such as Lim et al.'s [51] the tactile feedback does not provide directional information and is not in the form of tactile memory. In the industrial setting, Heinz et al. [52] presented how tactile feedback has been used in work gloves, bracelets, and shoes to provide workers with tactile information about their surrounding industrial setup. Tactile feedback in an industrial setting has been used for teleportation control systems [53]; mid-air haptic feedback and glove haptics have been used in industrial settings for better and safer usage of tooling [54]. However, the use of directional tactile memory for industrial workers has not been investigated, which could improve their efficiency and performance in industrial lines.

1.2. Tactile Memory Investigations

In experiments that investigated the effect of distracting tasks, such as articulacy suppression [43] on tactile memory, tactile feedback was applied to the hands and forearms of the participant [14,15,55]. In Gilson and Baddeley [43] a tactile stimulus was applied to the forearms and recalled after delays of 0, 3, 5, 10, 15, 30, 45, and 60 s while the subjects were counting backward. The results showed that tactile memory lasts for 10 s even when individuals are engaged in other tasks, and after 10 s the accuracy of delay decreased gradually until reaching an asymptote (after 45 s). Mahrer and Miles [14] investigated tactile memory in the hands while the first feedback was overwritten by a second instance of tactile feedback, but they did not investigate feedback on the back. Erp et al. [56] tested tactile memory in an experiment for the visually impaired by displaying objects through a navigation belt around the torso, distracting sounds were used as the distractor task. Thus, this paper will investigate directional tactile feedback, in several locations at the back of the participant, in the absence and presence of a high mental workload task.

The only experiment in the literature that the investigated tactile memory of the back was conducted by Howard et al. [57]. Tactile alerts of different frequencies were used on the driver's seat, mapping all the surroundings of the driver's vehicle. These tactile alerts varied in their update frequency from two to nine tactile updates in a 16 s interval, providing 8 s as the greatest time interval between the tactile alert and the time required to act [57]. The driver was instructed before the experiment to regain control when she/he saw an advancing minivan in the left lane. The results showed that the reaction time decreased when the tactile update's frequency increased. The tactile warnings in Howard et al.'s [57] study were mapping all the surroundings of the driver's vehicle, not the area of interest (AOI) to which the driver needed to be looking at any one time; hence, they were not employing directional tactile feedback. Also, the percentage of correct responses and the subject's acceptance of different tactile update frequencies were not assessed, as in this study.

1.3. Studies Contributions

In the previous sections, we have highlighted that to date, research has focused on tactile memory in the hands and forearms, neglecting the human, which is the objective of the experiments presented here.

The seat is the only location in constant contact with a driver and has the largest surface area; therefore, it can be easily used to provide directional tactile stimuli pointing to the area of interest (AOI), unlike the hands and forearms used in the past experiments [14,43].

Howard et al. [57] investigated the tactile memory of the back of the driver but mapped all the vehicle's surroundings and only provided up to 8 sec for the driver to respond. In particular, they did not investigate directional tactile memory within the AOI (this requires more precise pointing), nor whether directional tactile memory can be sustained beyond 8 s, as it is in the presented research (we test two different settings: 10 and 20 s).

Fitch et al. [58] examined tactile feedback on the back, and stated that the more tactile patterns, the faster they degrade. The percentage of mistakes in detecting tactile feedback rises as the number of patterns increases [58]. This suggests that the tactile patterns might need to be provided in a simple form to produce a long-lasting effect. This experiment will also provide findings into human abilities to retain directional tactile memory, to provide a future roadmap into how tactile patterns on the back can be set up for directional tactile memory.

In addition to this, we examined how to best administer the action cue to obtain faster responses (with a tactile or a visual cue) and the effect of a distraction task on directional tactile memory. We increased the precision of the configuration settings, extended the length required to sustain the directional tactile memory of the back, and introduced a mentally taxing task.

2. Experiment 1: Directional Tactile Memory

In this first experiment, our specific focus was on whether participants could remember the location of a cue delivered with precise directional tactile feedback (applied to the back of the volunteer) when the action cue modality varied between visual and tactile.

Also, to assess the longevity of this memory, we introduced different time intervals (10 s and 20 s) between the tactile location stimulus and the action cue. This allowed us to examine whether directional tactile memory extends beyond the 8 s limit suggested by Howard et al. [57].

In the first setting, the directional tactile stimulus (pressure in a location on the participant's back) corresponded to the AOI (location cue), and a visual stimulus (a yellow flashlight) was utilized to prompt the subject into action (visual action cue). In the second setting, we used the same location cue, and the action cue was provided by all motors vibrating simultaneously at the back of the user to trigger the subject into action (tactile action cue). Thus, we used an in between-subject design with repeated measures as shown in Table 1.

Table 1. In between-subject design with repeated measures.

Experiment 1 (Time in between Directional Tactile Feedback and Action Cue)	Setting 1: Action Cue Visual	Setting 2: Action Cue Tactile
Group 1 (10 s)	Location: Tactile cue Action cue: Visual (54 trials)	Location: Tactile cue Action cue: Tactile (54 trials)
Group 2 (20 s)	Location: Tactile cue Action cue: Visual (54 trials)	Location: Tactile cue Action cue: Tactile (54 trials)

In our first experimental setup, the directional tactile stimulus (pressure applied to a specific location on the participant's back) served as the location cue, while a visual stimulus (a yellow flashlight) was used to prompt the participant to take action (visual action cue).

In the second setup, we maintained the same location cue, but the action cue was provided by all motors vibrating simultaneously on the participant's back, prompting them to take action (tactile action cue).

To conduct this study, we employed an in between-subject design with repeated measures, as outlined in Table 1.

We investigated the following research question.

RQ: What is the effect of timing (10 s or 20 s) and action cue type (visual or tactile) on directional tactile memory pointing to the AOI at the back of the user?

H: The shorter the time, the better the memory recall. A visual action cue would outperform a tactile action cue due to a better stimulus-response compatibility and a second tactile action cue could affect the participant's recorded tactile memory.

Therefore, we hypothesize that combining tactile memory (location) and visual feedback (action) would lead to the best performances. Also, a shorter time between location and action cues would lead to a better performance.

2.1. Method Experiment 1

Participants: Forty volunteers were recruited through advertisements on social media, university distribution lists, and word of mouth. The only study inclusion criterion was being over 18 years of age. Participants were randomly allocated to an experimental group using a simple randomization technique (Kim Shin, 2014) [59]. A gender-balanced sample was not required as no hypothesis was formulated about the volunteers' characteristics, and the volunteers were accepted on a first-come, first-served basis. The average age was (M = 28.25, SD = 13.3), and gender was (M = 29, F = 11). The participants were volunteers and were not compensated for their time.

For sample size estimation, a prior power analysis was conducted using G*Power version 3.1, as shown by Faul et al. [60]. A study effect size f = 0.5 was used, indicating a moderate-to-large difference [61]. Multivariate analysis of variance (MANOVA) with three groups and three measurements, for a significance criterion of $\alpha = 0.05$ and Power = 0.95, the minimum sample size needed to test the study hypothesis was N = 27; thus, a sample size of 40 participants was considered more than sufficient.

The study University College London data protection number is Z6364106/2021/08/48.

2.1.1. Tools Experiment 1

Background Questionnaire: In the background questionnaire, the participants were asked about their age and gender.

NASA Task Load Index Questionnaire: The NASA task load index (NASA-TLX) questionnaire was administered after the trials. NASA TLX questionnaire was used to measure the six dimensions for the subjective experience of workload: mental demand, physical demand, temporal demand, perceived performance, effort, and frustration level [62]. The NASA-TLX questionnaires were scaled from 1 to 20, 1 being the lowest score and 20 the highest in every attribute measured. The attributes measured were mental demand, physical demand, temporal demand, performance, effort, and frustration [62].

Haptic feedback system: Nine coin vibration motors were embedded in a cushion placed in the back of the chair where the participants were seated Figure 1. They were arranged in a three-by-three matrix in a similar manner to the three-by-three matrix of buttons displayed on the screen as shown in Figure 2. The haptic motors are separated by a 40 mm inter-motor distance. The vibration motors operated at 3.3 V and were controlled by an Arduino Mega 2560. Each motor was connected using a 2n2222 transistor to the Arduino 5 V output and a digital output pin as shown in Figure 1. Each motor vibrated for 2 s when activated. A switch was used to start the vibration sequence.

Directional Tactile feedback: The directional tactile feedback was provided by one of the motors vibrating for 2 s. The motor location corresponded to the AOI (one of the 9 boxes, see Figure 2).

Visual Action Cue: The visual action cue was provided by a yellow flash that would disappear when the users clicked on any of the nine boxes.

Tactile Action Cue: All motors vibrated for 500 milliseconds at the same time at the back of the user to indicate the subject had to select a box.

Software: The PEBL (http://pebl.sourceforge.net/) open-source software program, was used to design the experiment interface and run the experiment computationally.

Figure 1. Experimental set-up.

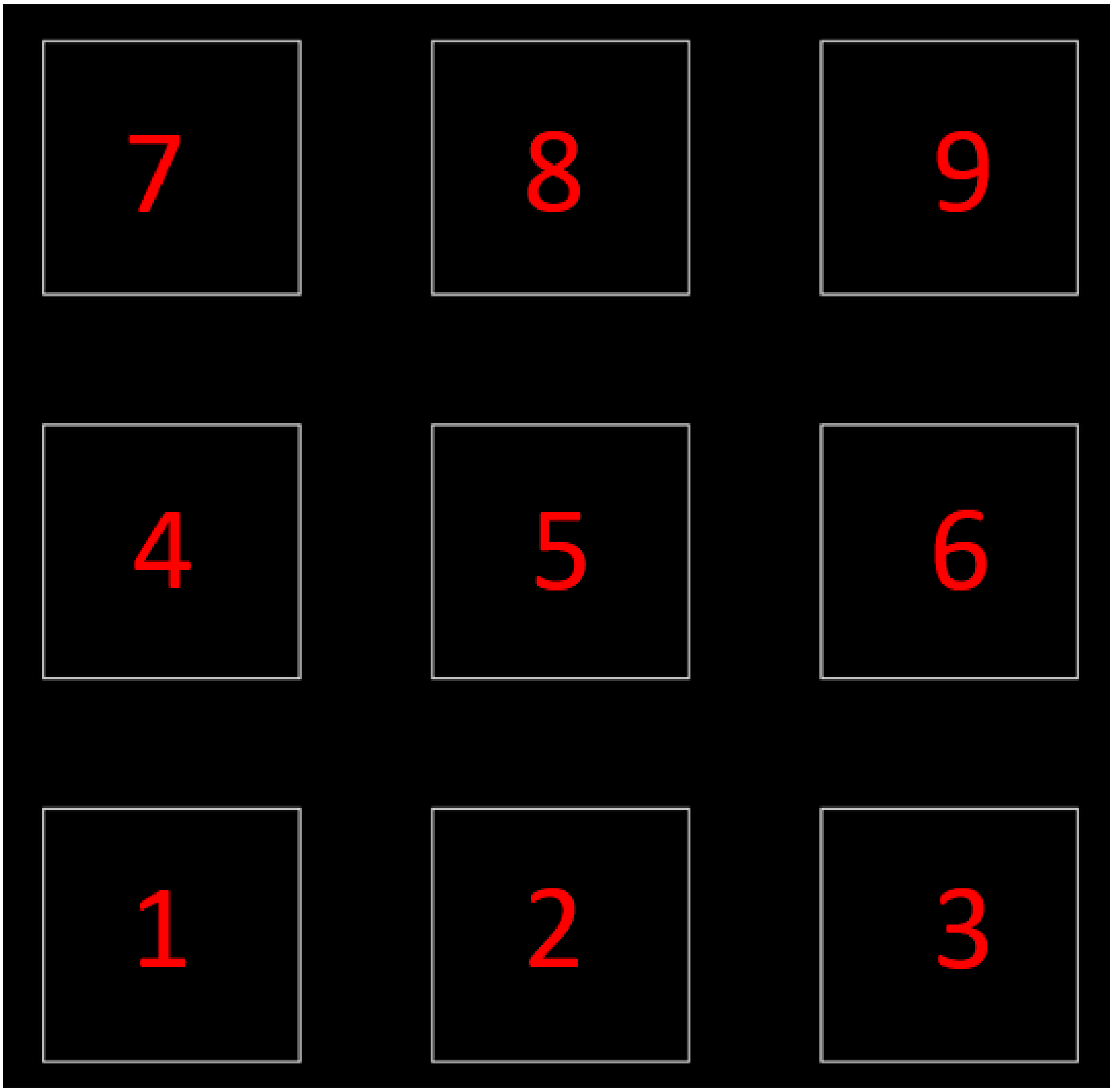

Figure 2. Three-by-three PEBL matrix visualized on the user's screen. The location of the motors on the user's back corresponds to the PEBL matrix numbered buttons.

2.1.2. Procedure Experiment 1

On their arrival, participants were greeted, asked to provide their informed consent, and allocated to a group at random.

In group one, as shown in Figure 3, the subjects received the action cue after the directional tactile feedback with a gap of 10 s, and in group two after a gap of 20 s. The experimenters also highlighted verbally that they could withdraw at any time. Each volunteer was asked to sit on the chair with the tactile apparatus, with a 15″ screen, keyboard, and mouse placed on a desk in front of them. First, she/he was asked to fill out the background questionnaire. Following this, the sequence of stimuli started, and each user was asked to click on the box that corresponded to the directional tactile location cue provided on the back when prompted by the action cue. Each subject received fifty-four trials. After the experiment, the volunteers were asked to fill out the NASA TLX, and were thanked for their participation.

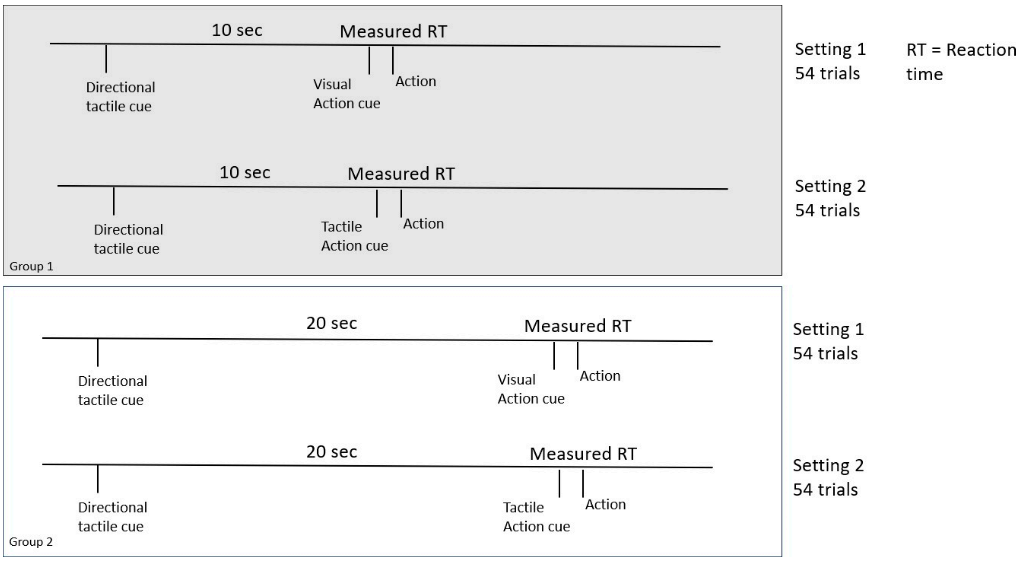

Figure 3. Experimental flow.

2.1.3. Study Variables

The independent variables were as follows.

Stimulus, the type of action cue administered. It can be visual or tactile.

Time, this refers to the experiment settings of 10 s or 20 s between the location cue and the action cue.

Trial, volunteer's trial number, how many times the volunteers had to select an AOI on the screen, 54 times.

During the experiment, we recorded the following measures (dependent variables).

Reaction time (RT), this is the time from the end of the location cue administration until the user clicks on the box on the screen in each trial, measured in milliseconds.

Absolute time (ART), this is the time measured from the start of the experiment until the last button press is recorded, measured in milliseconds.

Error, this is the number of times the user made an error (did not click on the correct box). Table 2 shows all the different variables used in the experiment.

Table 2. Experiment 1 variables.

Independent Variables (IV)	Dependent Variables (DV)
Stimulus (visual or tactile) Time (10 s or 20 s) Trial (1 to 54)	Absolute Reaction Time (ART) Reaction time (RT) Error

2.1.4. Data Analysis Experiment 1

IBM SPSS V28 statistical analysis software was used to analyze the data. When a participant did not give any response after the tactile feedback, the data were considered as outliers, and removed. Any other outliers were not removed, and considered as natural variations in the dataset, as the dependent variables Error and ART were normally distributed. The skewness of Error was found to be 0.020, and the skewness of ART was 0.732. The skewness of RT was found to be 10.12, indicating that the distribution was right-skewed. Although, RT was not a normal distribution it was considered a natural variation as there was a longer reaction time when a distractor task was included, or when a second instance of tactile feedback was used as an action cue.

2.1.5. Results Experiment 1

A Pearson correlation showed that the dependent variable Error was correlated with ART and RT, see Table 3. Thus, a multivariate analysis of variance (MANOVA) could be utilized to examine the effect of stimulus, time, and trials on the dependent variables ART, RT, and Error, see Table 2. It showed a significant multivariate effect for Time (Pillai's Trace = 0.424, F(6) = 132.261, $p \leq 0.001$) and Trial (Pillai's Trace = 0.934, F(171) = 11.716, $p \leq 0.001$). However, the Stimulus was not significant. Also, there was a significant interaction between Time and Trial (Pillai's Trace = 0.294, F(318) = 1.516, $p \leq 0.001$). The Bonferroni correction is reported in Table 4.

Table 3. Pearson correlation.

Pearson Correlation	Stimulus	Time	Trial	Error	ART
Stimulus	1				
Time	−0.896 **				
Trial	−0.116 **	0.097 **			
Error	0.118 **	−0.091 **	−0.169 **		
ART	0.066 **	0.075 **	0.817 **	−0.060 *	
RT	0.192 **	−0.149 **	−0.082 **	0.097 **	−0.003

** Correlation is significant at 0.01 level (2-tailed). * Correlation is significant at 0.05 level (2-tailed).

Table 4. Tests of between-subject effects.

Source	Dep Variable	Type III Sum of Sq.	df	Mean Sq.	F	Sig.	Partial Eta Sq.
Time	Error	0.692	2	0.346	1.457	0.23	0.002
	ART	3×10^{13}	2	1.48×10^{13}	529.4	<0.001	0.4
	RT	1.2×10^{8}	2	61,723,689	2.335	0.097	0.003
Trial	Error	28	57	0.49	2.07	<0.001	0.07
	ART	1.6×10^{14}	57	2.7×10^{12}	99.08	0	0.79
	RT	3.7×10^{9}	57	65,197,953	2.466	<0.001	0.09
Time * Trial	Error	22.6	106	6.59×10^{10}	2.4	0.76	0.06
	ART	7×10^{12}	106	6.59×10^{10}	2.36	<0.001	0.15
	RT	3.7×10^{9}	106	34,989,947	1.32	0.018	0.087

The descriptive statistics are in Table 5, showing that group one with setting 1, which had a visual action cue, had fewer errors and faster reactions compared to setting 2, which had a tactile action cue. This confirmed the earlier hypothesis that a shorter second tactile feedback would affect the individual's tactile memory.

Table 5. Descriptive statistics for Experiment 1.

	Setting 1: Visual		Setting 2: Tactile	
	Mean	STD	Mean	STD
Error	1.44	0.49	1.56	0.49
ART	647.5	367.2	699.6	417.3
RT	1.04	1.5	6.6	3.65

3. Experiment 2: Distractor Task

On the strength of the previous results, a follow-up experiment was run in which a distraction task (playing the game Tetris), which requires pattern matching a shape into a grid as fast and accurately as possible, was used to increase the mental load exerted on the subjects and assess the extent to which their tactile memory was still effective, although they were immersed in another task.

Thus, our experiment increased the cognitive load and formulated the following research question and hypothesis.

RQ: Does a mentally taxing task (playing Tetris) affect directional tactile memory?

H: We hypothesize that a higher mental load increases the reaction time and the number of errors made.

3.1. Method Experiment 2

Experiment 2 was run like Experiment 1 and on the same subjects, but using only a tactile location cue and a visual action cue. The volunteers were divided into two groups according to the timing (10 s or 20 s) between the location cue and the visual action cue as in Experiment 1. Thus, the results can be compared (repeated measures). The subjects were asked to play Tetris until they saw the visual action cue with their peripheral vision. The same tactile feedback apparatus was utilized, but with two monitors, one for the Tetris game on the right inside and one for the matrix of boxes on the left, see Figure 4. The same background questionnaire was administered before the test and the NASA TLX was again provided after the experiment. The volunteers completed 54 trials.

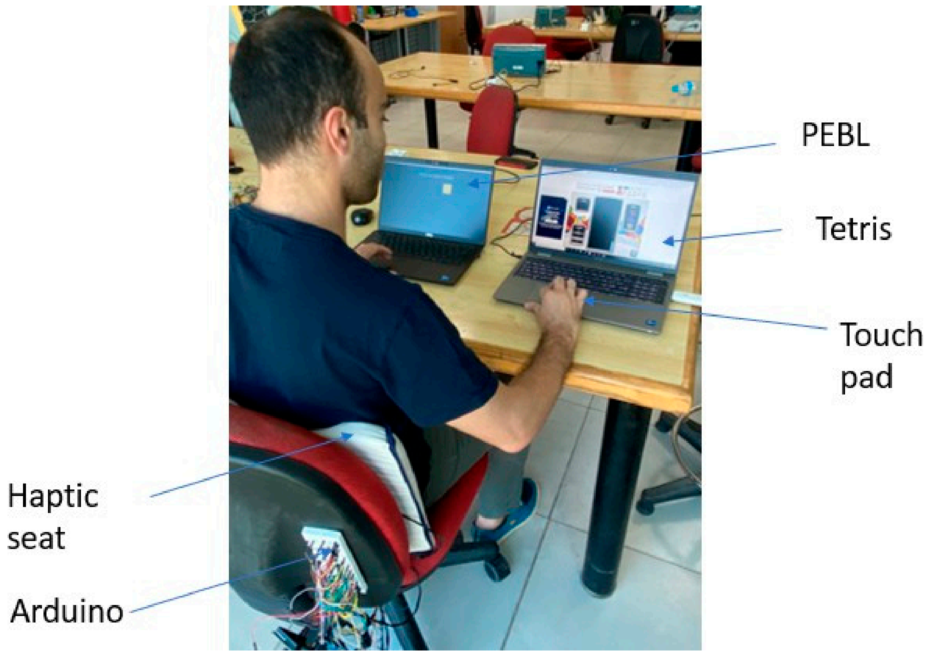

Figure 4. Experiment 2 with a distracting task.

3.1.1. Additional Tool

Tetris game: Tetris is a puzzle-like video game where the user needs to arrange falling blocks of different shapes to best fill a full line in the provided grid.

3.1.2. Experiment 2 Variables

The variables considered for Experiment 2 were the same as in Experiment 1, where the independent variable *Experiment* (1 or 2) was introduced to compare the two experiments. The *Stimulus* variable was not utilized as we used only a visual action cue.

3.1.3. Data Analysis Experiment 2

IBM SPSS v28 was used for statistical analysis. A one-way analysis of variance (ANOVA) was utilized to see whether there was a difference between RT and Error between Experiment 1 and Experiment 2. A power calculation showed that for a medium effect (0.5-using Cohen et al.'s [61] criteria) $\alpha = 0.05$ and Power = 0.80, the minimum sample size was 34. Thus, the sample size of N = 40 utilized for this comparison is adequate. The NASA TLX questionnaire was also administered in Experiment 2 and the results are illustrated in Figure 5. A one-way ANOVA was run to compare the mean results of the NASA TXL between the two experiments.

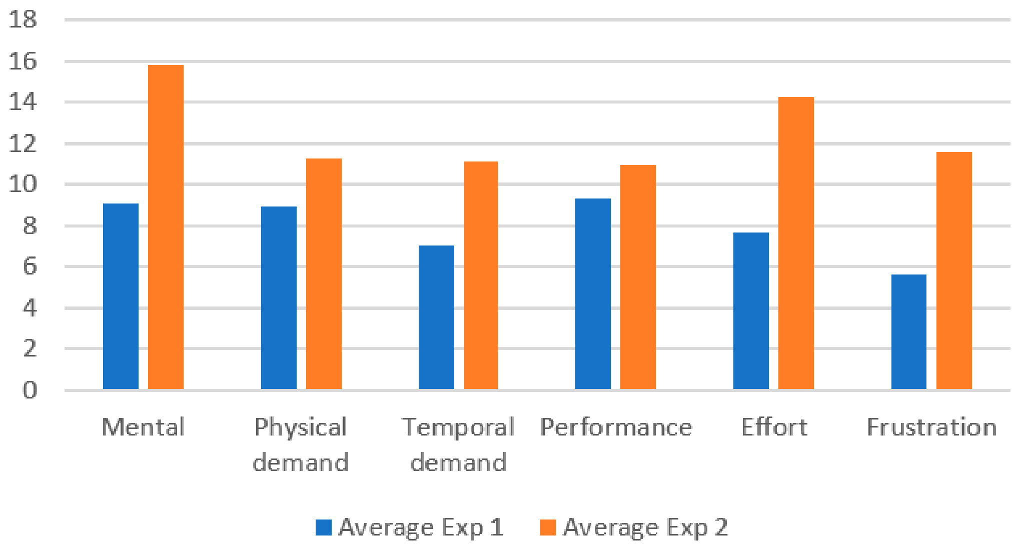

Figure 5. NASA TLX comparison of the results between Experiment 1 and Experiment 2.

4. Results Comparison for Experiments 1 and 2

4.1. Reaction Time and Errors Comparison

A one-way ANOVA showed a significant difference between Experiments 1 and 2 for RT $F(1376) = 9.537$, $p = 0.002 < 0.001$; and Error $F(1376) = 4.929$, $p = 0.027 < 0.05$. Considering the descriptive statistics in Table 6 the results show that in Experiment 2, the number of errors and the reaction time significantly increased.

Table 6. Descriptive statistics for Experiment 2.

	Error		RT	
	Mean	**STD**	**Mean**	**STD**
Experiment 1	1.49	0.5	1509.06	2289.98
Experiment 2	1.78	0.42	2964.89	3546.82

4.2. NASA TLX Comparison

A Shapiro–Wilk test was run on the NASA TLX variables. It was found that most variables were skewed, see Table 7.

Thus, a Mann–Whitney test was used to compare the NASA TLX questionnaire administered after Experiment 1 and Experiment 2. The results indicated that there was no significant difference between the perceived physical and temporal demands, nor was the performance perceived differently. However, there was a significant difference in the perceived mental load $z = -2.788$, $p = 0.005$; effort $z = -3.118$, $p = 0.002$; and frustration $z = -2.298$, $p = 0.022$.

Table 7. Shapiro–Wilk test of normality.

Shapiro–Wilk	Statistic	df	Sig.
Mental	0.954	43	0.084
Physical demand	0.921	43	0.006
Temporal demand	0.913	43	0.003
Performance	0.955	43	0.089
Effort	0.963	43	0.178
Frustration	0.855	43	<0.001

In Table 6, the descriptive statistics show that participants perceived Experiment 2 as more mentally, physically, and temporally demanding; it required more effort and was more frustrating, and the reaction time and errors accordingly increased. However, the participants similarly judged their performances, see Figure 5.

5. Discussion

This study investigated whether tactile feedback directed at the back of individuals could be retained for up to 20 s to direct them to nine locations on a screen. Additionally, we examined the effect of using a visual versus a tactile action cue on tactile memory. We hypothesized that individuals receiving directional tactile feedback would perform better (in terms of reaction time and number of errors) with a 10 s delay compared to a 20 s delay due to the expected deterioration of tactile memory over a longer period. We also hypothesized that performance would be better with a visual action cue compared to a second tactile action cue, as the second tactile feedback might overwrite the first. Finally, we hypothesized that adding a mentally taxing task would deteriorate performance compared to an experiment without such a task. This hypothesis is crucial for understanding how distractions affect tactile memory in real-world settings like industrial environments or autonomous vehicles.

The results revealed that directional tactile memory could be retained for both 10 and 20 s. As shown in Table 4, the duration (10 vs. 20 s) did not have a statistically significant effect on errors or reaction time. However, the trial number had a statistically significant effect, indicating that participants improved as the trials progressed. Contrary to our initial hypothesis, tactile memory survived for both 10 and 20 s without a statistical difference in performance. This finding opens up the possibility of investigating how long tactile memory can be retained while maintaining performance in different tasks. This would be beneficial if applied to individuals performing another task such as driving, as the tactile feedback would not need to be provided every 10 s which would cause a mental overload [63,64], irritation [44], and the second tactile feedback would overwrite the first [14].

In previous studies, Picard et al. [65] explored short-term tactile memory by presenting patterns to the hand and measuring recall, finding a memory span of 2.18 s. Similarly, Gilson et al. [43] examined short-term tactile memory by assessing recall of the location of a tactile stimulus on the forearm after various delays while participants counted backwards. Gilson et al. reported that tactile memory lasted up to 10 s and performance asymptoted after 45 s, suggesting that information did not completely disappear before this duration. Our findings suggest that directional tactile memory to the back can survive up to 20 s, suggesting an intriguing avenue for future research. It would be valuable to investigate how long tactile memory can be retained when provided directionally to the back, expanding our understanding beyond the contexts studied by Picard et al. [65] and Gilson et al. [43].

Humacher et al. [66] and Gilson et al. [43] investigated the effect of distracting tasks on tactile memory; however, the tactile feedback was directed to the subject's hands and forearms only, not towards the back as in our experiment. Gilson et al. [43] found that the mean error in locating the position of tactile feedback increased significantly with a distraction task (counting backward). Specifically, after 30 s, the mean error was 17 cm without a distraction task and 24 cm with a distraction task. In our study, comparing the results of Experiment 1 (without a distraction task) and Experiment 2 (with a distraction task), we found that performance deteriorated with the added cognitive load. As shown in Table 6, the mean error increased from 1.49 to 1.78, and reaction time increased from 1.5 s to 3 s. This demonstrates the effect of distraction on tactile memory retention and has implications for human–machine interaction systems in self-driving vehicles or industrial settings. The NASA TLX questionnaire results further confirmed that participants found the task significantly more mentally challenging, requiring more effort, and frustrating when combined with a distracting task (see Figure 5).

Previous studies by Mahrer et al. [14] showed that the sensory traces of the first tactile sequence are overwritten by subsequent tactile feedback. Our hypothesis supported this finding. Mahrer et al. found that the correct recognition rate of tactile patterns improved from 1.69 to 2 when tactile interference was included. Table 5 shows that when a visual action cue was used, the mean error was 1.44, which increased to 1.56 when tactile feedback was used as the action cue. Reaction time increased from 1.04 s to 6.6 s when tactile feedback was used, indicating that secondary tactile feedback deteriorates tactile memory. This guides future designs to use visual or audio modalities as action cues accompanying tactile memory.

Our experiment showed that directional tactile memory when applied to the back can survive up to 20 s without a significant effect on the measured performance, contrary to previous studies that focused on the hands and forearms. These studies, including Gilson et al. [43], showed that performance deteriorated significantly after 10 s, especially with a distraction task. Other tactile memory experiments [14] had shown that a second instance of tactile feedback overwrites the first and deteriorates tactile memory; this was proven to also be the case with the directional tactile memory of the back.

5.1. Theoretical Implication

Directional tactile memory has been successfully used for the first time in the research presented here to attempt to direct subjects' attention to nine different locations on the screen. The findings validate the possibility of using the directional tactile memory of the back in different applications, as it has been proven to last up to 20 s. The design of the tactile feedback would need to use audio or visual cues as the action cue to prevent the initial tactile sensory traces from being overwritten.

5.2. Limitations and Future Work

The study findings could be further extended. Although 4 cm was used as inter-motor distance as recommended by Jones et al. [36], subjects in some trials failed to distinguish the location of a vibrating motor and mistook it for a neighboring row or column.

The subjects, on average, could identify directions using the tactile setup. However, at times, there was confusion between neighboring rows and columns. This could perhaps be remedied by having two different frequencies used in the tactile feedback of neighboring rows and columns.

Future work could also try to direct users to blind spots and increase the number of locations pointed to on the screen. Additionally, a longer delay in the action cue, beyond 20 s, could be studied. As a further delay could have a statistically significant effect on tactile memory. Further research is needed to confirm the results in the context of autonomous vehicles.

The experiments presented in this paper were conducted in a lab and could be repeated in a driving simulator to assess the driving performance when tactile memory is used, mindful that a higher cognitive load deteriorates directional tactile memory. The area of interest (AOI) could be identified in the driving scene, industrial lines, construction sites, and for the visually impaired or any task being performed, and traced to the driver's back seat to provide a directional cue that the individual should focus on when performing the task.

6. Conclusions

A human–machine interaction system that capitalizes on directional tactile memory is presented and validated in this paper. The results demonstrate that directional tactile feedback on the back of the users can be utilized to point people to nine different locations on the screen, with tactile memory lasting for up to 20 s, with no statistical difference in the performance between 10 and 20 s.

Due to the experimental setup, the mean reaction time was 1 s compared to 6.6 s when the experiment had a tactile action cue showing how severely a second tactile cue affects the performance. Further investigations are needed to better understand how long tactile memory can survive in different settings such as autonomous vehicles, industrial lines, and surgical rooms. It has been shown that a distractor task in this experiment affected the participant's tactile memory and the participant's perceived mental load, effort, and frustration increased with the presence of a distractor task.

Therefore, tactile memory has shown that it can direct individuals in different tasks. However, further research is needed to understand how long directional tactile memory can survive, and how it can cope with different types of tasks, and the best pattern and frequency setup that would be suitable for every specific task.

Although this is the first experiment investigating the directional tactile memory of the back and the effect of a complicated task on tactile memory and task performance, more work needs to be performed to understand the effect of complicated tasks such as driving, or industrial machine operation, on tactile memory and the performance of different tasks.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available as this study belongs to an ongoing research project.

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Abbreviations

The following abbreviations are used in this manuscript:

AOI	Area of Interest AOI
ART	Absolute Reaction
Time RT	Reaction Time

References

1. Friedrich, D.T.; Dürselen, L.; Mayer, B.; Hacker, S.; Schall, F.; Hahn, J.; Hoffmann, T.K.; Schuler, P.J.; Greve, J. Features of haptic and tactile feedback in TORS-a comparison of available surgical systems. *J. Robot. Surg.* **2018**, *12*, 103–108. [CrossRef] [PubMed]
2. Gallace, A.; Spence, C. The cognitive and neural correlates of tactile memory. *Psychol. Bull.* **2009**, *135*, 380. [CrossRef]
3. Eguchi, R.; Vacek, D.; Godzinski, C.; Okamura, A.M. Between-Tactor Display Using Dynamic Tactile Stimuli for Directional Cueing in Vibrating Environments. *IEEE Trans. Haptics* 2023, *early access*. [CrossRef]

4. Schroeter, R.; Steinberger, F. Pokémon DRIVE: Towards increased situational awareness in semi-automated driving. In Proceedings of the 28th Australian Conference on Computer-Human Interaction, Tasmania, Australia, 29 November–2 December 2016; pp. 25–29.
5. Lutnyk, L.; Rudi, D.; Meier, E.; Kiefer, P.; Raubal, M. FlyBrate: Evaluating Vibrotactile Cues for Simulated Flight. *Int. J. Hum. Comput. Interact.* **2023**, *39*, 2374–2391. [CrossRef]
6. Chaudary, B.; Pohjolainen, S.; Aziz, S.; Arhippainen, L.; Pulli, P. Teleguidance-based remote navigation assistance for visually impaired and blind people—Usability and user experience. *Virtual Real.* **2023**, *27*, 141–158. [CrossRef] [PubMed]
7. Petermeijer, S.M.; Cieler, S.; De Winter, J.C. Comparing spatially static and dynamic vibrotactile take-over requests in the driver seat. *Accid. Anal. Prev.* **2017**, *99*, 218–227. [CrossRef] [PubMed]
8. Salzer, Y.; Oron-Gilad, T.; Ronen, A.; Parmet, Y. Vibrotactile "on-thigh" alerting system in the cockpit. *Hum. Factors* **2011**, *53*, 118–131. [CrossRef] [PubMed]
9. Schwalk, M.; Kalogerakis, N.; Maier, T. Driver support by a vibrotactile seat matrix—Recognition, adequacy and workload of tactile patterns in take-over scenarios during automated driving. *Procedia Manuf.* **2015**, *3*, 2466–2473. [CrossRef]
10. Erp, V.; Jan, B.; Veltman, J.; van Veen, H.; Oving, A. *Tactile Torso Display as Countermeasure to Reduce Night Vision Goggles Induced Drift*; Defense Technical Information Center: Fort Belvoir, VA, USA, 2003.
11. Fu, L.; Huang, H.; Berscheid, L.; Li, H.; Goldberg, K.; Chitta, S. Safe self-supervised learning in real of visuo-tactile feedback policies for industrial insertion. In Proceedings of the 2023 IEEE International Conference on Robotics and Automation (ICRA), London, UK, 29 May–2 June 2023; pp. 10380–10386.
12. Palagi, M.; Santamato, G.; Chiaradia, D.; Gabardi, M.; Marcheschi, S.; Solazzi, M.; Frisoli, A.; Leonardis, D. A mechanical hand-tracking system with tactile feedback designed for telemanipulation. *IEEE Trans. Haptics* **2023**, *16*, 594–601. [CrossRef]
13. Huang, Y.; Hammad, A.; Zhu, Z. Providing proximity alerts to workers on construction sites using Bluetooth Low Energy RTLS. *Autom. Constr.* **2021**, *132*, 103928. [CrossRef]
14. Mahrer, P.; Miles, C. Recognition memory for tactile sequences. *Memory* **2002**, *10*, 7–20. [CrossRef] [PubMed]
15. Miles, C. Tactile short-term memory revisited. *Memory* **1996**, *4*, 655–668. [CrossRef]
16. Vo, D.B.; Brewster, S. Investigating the effect of tactile input and output locations for drivers' hands on in-car tasks performance. In Proceedings of the 12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Virtual, 21–22 September 2020; pp. 1–8.
17. Roozendaal, J.; Johansson, E.; Winter, J.d.; Abbink, D.; Petermeijer, S. Haptic lane-keeping assistance for truck driving: A test track study. *Hum. Factors* **2020**, *63*, 1380–1395. [CrossRef] [PubMed]
18. Williams, B.; Garton, A.E.; Headleand, C.J. Exploring Visuo-haptic Feedback Congruency in Virtual Reality. In Proceedings of the 2020 International Conference on Cyberworlds (CW), Caen, France, 29 September–1 October 2020; pp. 102–109.
19. Di Campli San Vito, P.; Brewster, S.; Pollick, F.; Thompson, S.; Skrypchuk, L.; Mouzakitis, A. Purring Wheel: Thermal and Vibrotactile Notifications on the Steering Wheel. In Proceedings of the 2020 International Conference on Multimodal Interaction, Online, 25–29 October 2020; pp. 461–469.
20. Caldwell, D.G.; Lawther, S.; Wardle, A. Multi-modal cutaneous tactile feedback. In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS'96, Osaka, Japan, 4–8 November 1996; Volume 2, pp. 465–472.
21. Krüger, M.; Wiebel-Herboth, C.B.; Wersing, H. Tactile encoding of directions and temporal distances to safety hazards supports drivers in overtaking and intersection scenarios. *Transp. Res. Part F Traffic Psychol. Behav.* **2021**, *81*, 201–222. [CrossRef]
22. Krüger, M.; Wiebel-Herboth, C.B.; Wersing, H. The Lateral Line: Augmenting Spatiotemporal Perception with a Tactile Interface. In Proceedings of the Augmented Humans International Conference, Kaiserslautern, Germany, 16–17 March 2020; pp. 1–10.
23. Sasikumar, P. Haptic Contact in Immersive 360° Cinematic Environment. Master's Thesis, University of Canterbury, Christchurch, New Zealand, 2018.
24. Alotaibi, Y. The use of Electrotactile Feedback in Cars. In Proceedings of the 33rd International BCS Human Computer Interaction Conference 33, Newcastle, UK, 6–10 July 2020; pp. 51–54.
25. Jung, J.; Lee, S.; Hong, J.; Youn, E.; Lee, G. Voice+ Tactile: Augmenting In-vehicle Voice User Interface with Tactile Touchpad Interaction. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, Honolulu, HI, USA, 25–30 April 2020; pp. 1–12.
26. Hogan, F.R. Reactive Manipulation with Contact Models and Tactile Feedback. Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, MA, USA, 2020.
27. Zhu, Y.; Liu, W.; Zhu, D. Design Research on Vibration Tactile Feedback in Vehicle Navigation Information Application. In Proceedings of the Eighth International Workshop of Chinese CHI, Honolulu, HI, USA, 25–30 April 2020; pp. 47–56.
28. Zhu, A.; Cao, S.; Yao, H.; Jadliwala, M.; He, J. Can Wearable Devices Facilitate a Driver's Brake Response Time in a Classic Car-Following Task? *IEEE Access* **2020**, *8*, 40081–40087. [CrossRef]
29. Shin, J.G.; Kim, S.H. Intelligibility of Haptic Signals in Vehicle Information Systems. *Sensors* **2021**, *21*, 4583. [CrossRef] [PubMed]
30. Cooper, N.; Millela, F.; Cant, I.; White, M.D.; Meyer, G. Transfer of training—Virtual reality training with augmented multisensory cues improves user experience during training and task performance in the real world. *PLoS ONE* **2021**, *16*, e0248225. [CrossRef]
31. Hölzl, R.; Steckhan, L.; Lehsing, C.; Savage, S.W.; Bowers, A.R. Driving with hemianopia VIII: Effects of a vibro-tactile assistance system on safety and gaze behavior in pedestrian crossing situations. *Safety* **2021**, *7*, 18. [CrossRef]

32. Geitner, C.; Biondi, F.; Skrypchuk, L.; Jennings, P.; Birrell, S. The comparison of auditory, tactile, and multimodal warnings for the effective communication of unexpected events during an automated driving scenario. *Transp. Res. Part F Traffic Psychol. Behav.* **2019**, *65*, 23–33. [CrossRef]
33. Laßmann, P.; Othersen, I.; Fischer, M.S.; Reichelt, F.; Jenke, M.; Tüzün, G.J.; Bauerfeind, K.; Mührmann, L.; Maier, T. Driver's Experience and Mode Awareness in between and during Transitions of different Levels of Car Automation. In Proceedings of the Human Factors and Ergonomics Society Europe Chapter 2019 Annual Conference, Nantes, France, 2–4 October 2019.
34. Petermeijer, S.M.; De Winter, J.C.; Bengler, K.J. Vibrotactile displays: A survey with a view on highly automated driving. *IEEE Trans. Intell. Transp. Syst.* **2015**, *17*, 897–907. [CrossRef]
35. Fellah, K.; Guiatni, M. Tactile display design for flight envelope protection and situational awareness. *IEEE Trans. Haptics* **2018**, *12*, 87–98. [CrossRef]
36. Jones, L.A.; Sarter, N.B. Tactile displays: Guidance for their design and application. *Hum. Factors* **2008**, *50*, 90–111. [CrossRef] [PubMed]
37. Alirezaee, P.; Weill-Duflos, A.; Schlesinger, J.J.; Cooperstock, J.R. Exploring the effectiveness of haptic alarm displays for critical care environments. In Proceedings of the 2020 IEEE Haptics Symposium (HAPTICS), Crystal City, VA, USA, 28–31 March 2020; pp. 948–954.
38. Edet, U.; Mann, D.D. Evaluation of warning methods for remotely supervised autonomous agricultural machines. *J. Agric. Saf. Health* **2022**, *28*, 1–17. [CrossRef] [PubMed]
39. Horton, E.L.; Renganathan, R.; Toth, B.N.; Cohen, A.J.; Bajcsy, A.V.; Bateman, A.; Jennings, M.C.; Khattar, A.; Kuo, R.S.; Lee, F.A.; et al. A review of principles in design and usability testing of tactile technology for individuals with visual impairments. *Assist. Technol.* **2017**, *29*, 28–36. [CrossRef] [PubMed]
40. Wall, S.; Brewster, S. Feeling what you hear: Tactile feedback for navigation of audio graphs. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Montréal, QC, Canada, 22–27 April 2006; pp. 1123–1132.
41. Liu, G.; Yu, T.; Yu, C.; Xu, H.; Xu, S.; Yang, C.; Wang, F.; Mi, H.; Shi, Y. Tactile compass: Enabling visually impaired people to follow a path with continuous directional feedback. In Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, Yokohama, Japan, 8–13 May 2021; pp. 1–13.
42. Teizer, J.; Allread, B.S.; Fullerton, C.E.; Hinze, J. Autonomous pro-active real-time construction worker and equipment operator proximity safety alert system. *Autom. Constr.* **2010**, *19*, 630–640. [CrossRef]
43. Gilson, E.Q.; Baddeley, A. Tactile short-term memory. *Q. J. Exp. Psychol.* **1969**, *21*, 180–184. [CrossRef] [PubMed]
44. Lylykangas, J.; Surakka, V.; Salminen, K.; Farooq, A.; Raisamo, R. Responses to visual, tactile and visual–tactile forward collision warnings while gaze on and off the road. *Transp. Res. Part F Traffic Psychol. Behav.* **2016**, *40*, 68–77. [CrossRef]
45. Scott, J.; Gray, R. A comparison of tactile, visual, and auditory warnings for rear-end collision prevention in simulated driving. *Hum. Factors* **2008**, *50*, 264–275. [CrossRef]
46. Politis, I.; Brewster, S.; Pollick, F. Language-based multimodal displays for the handover of control in autonomous cars. In Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Nottingham, UK, 1–3 September 2015; pp. 3–10.
47. Calhoun, G.L.; Draper, M.H.; Guilfoos, B.J.; Ruff, H.A. Tactile and aural alerts in high auditory load UAV control environments. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting, Orlando, FL, USA, 26–30 September 2005; Sage Publications: Los Angeles, CA, USA, 2005; Volume 49, pp. 145–149.
48. Wickens, C.D. Multiple resources and mental workload. *Hum. Factors* **2008**, *50*, 449–455. [CrossRef] [PubMed]
49. Gilson, R.D.; Redden, E.S.; Elliott, L.R. *Remote Tactile Displays for Future Soldiers*; Technical Report; University of Central Florida: Orlando, FL, USA, 2007.
50. Yadav, N.; Sadeghi, N.; Kang, J. Five factors affecting the on-body placement of wearable tactile safety promotion device for construction workers-on-foot. *Constr. Innov.* **2022**, *24*, 537–557. [CrossRef]
51. Lim, S.; Yang, X. Real-time vibrotactile feedback system for reducing trunk flexion exposure during construction tasks. *Appl. Ergon.* **2023**, *110*, 104019. [CrossRef] [PubMed]
52. Heinz, M.; Röcker, C. Feedback presentation for workers in industrial environments—Challenges and opportunities. In Proceedings of the Machine Learning and Knowledge Extraction: Second IFIP TC 5, TC 8/WG 8.4, 8.9, TC 12/WG 12.9 International Cross-Domain Conference, CD-MAKE 2018, Hamburg, Germany, 27–30 August 2018; Proceedings 2; Springer: Berlin/Heidelberg, Germany, 2018; pp. 248–261.
53. Dekker, I.; Kellens, K.; Demeester, E. Design and Evaluation of an Intuitive Haptic Teleoperation Control System for 6-DoF Industrial Manipulators. *Robotics* **2023**, *12*, 54. [CrossRef]
54. Piviotti, M. Providing Force and Vibrotactile Feedback with Haptic Devices for Simulating Industrial Tools in Immersive Virtual Reality. Ph.D. Thesis, Politecnico di Torino, Torino, Italy, 2021.
55. Marsh, J.E.; Vachon, F.; Sörqvist, P.; Marsja, E.; Röer, J.P.; Richardson, B.H.; Ljungberg, J.K. Irrelevant changing-state vibrotactile stimuli disrupt verbal serial recall: Implications for theories of interference in short-term memory. *J. Cogn. Psychol.* **2024**, *36*, 78–100. [CrossRef]
56. Erp, J.B.v.; Paul, K.I.; Mioch, T. Tactile working memory capacity of users who are blind in an electronic travel aid application with a vibration belt. *ACM Trans. Access. Comput. (TACCESS)* **2020**, *13*, 1–14. [CrossRef]

57. Howard, M.; Sundareswara, R.; Daily, M.; Bhattacharyya, R.; Kaplan, S.; Mundhenk, N.; Lee, C.; Neely, H. Using tactile displays to maintain situational awareness during driving. In Proceedings of the 2013 IEEE International Multi-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support (CogSIMA), San Diego, CA, USA, 25–28 February 2013; pp. 228–237.
58. Fitch, G.M.; Hankey, J.M.; Kleiner, B.M.; Dingus, T.A. Driver comprehension of multiple haptic seat alerts intended for use in an integrated collision avoidance system. *Transp. Res. Part F Traffic Psychol. Behav.* **2011**, *14*, 278–290. [CrossRef]
59. Kim, J.; Shin, W. How to do random allocation (randomization). *Clin. Orthop. Surg.* **2014**, *6*, 103–109. [CrossRef] [PubMed]
60. Faul, F.; Erdfelder, E.; Lang, A.G.; Buchner, A. G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav. Res. Methods* **2007**, *39*, 175–191. [CrossRef] [PubMed]
61. Cohen, J. Statistical power analysis. *Curr. Dir. Psychol. Sci.* **1992**, *1*, 98–101. [CrossRef]
62. Gawron, V.J. *Human Performance, Workload, and Situational Awareness Measures Handbook*; CRC Press: Boca Raton, FL, USA, 2008.
63. DeLucia, P.R.; Greenlee, E.T. Tactile vigilance is stressful and demanding. *Hum. Factors* **2022**, *64*, 732–745. [CrossRef] [PubMed]
64. Guettaf, A. Understanding and Designing Tactile Feedback Interaction for Secondary Tasks. Ph.D. Thesis, Université Polytechnique Hauts-de-France, Valenciennes, France, 2022.
65. Picard, D.; Monnier, C. Short-term memory for spatial configurations in the tactile modality: A comparison with vision. *Memory* **2009**, *17*, 789–801. [CrossRef]
66. Hutmacher, F.; Kuhbandner, C. Long-term memory for haptically explored objects: Fidelity, durability, incidental encoding, and cross-modal transfer. *Psychol. Sci.* **2018**, *29*, 2031–2038. [CrossRef] [PubMed]