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An experimental setup to test dual-joystick directional responses to vibrotactile stimuli

Lorenzo Scalera, Stefano Seriani, Paolo Gallina, Massimiliano Di Luca and Alessandro Gasparetto

Abstract—In this paper we investigate the influence of the location of vibrotactile stimulation in triggering the response made using two handheld joysticks. In particular, we compare performance with stimuli delivered either using tactors placed on the palm or on the back of the hand and with attractive (move toward the vibration) or repulsive prompts (move away from the vibration). The experimental set-up comprised two joysticks and two gloves, each equipped with four pager motors along the cardinal directions.
In different blocks, fifty-three volunteers were asked to move the joysticks as fast as possible either towards or away with respect to the direction specified by a set of vibrating motors. Results indicate that participants performed better with attractive prompts (i.e. responses were faster and with fewer errors in conditions where participants were asked to move the joysticks in the direction of the felt vibration) and that the stimulation delivered on the back of the hand from the gloves gives better results than the stimulation on the palm delivered by the joysticks. Finally, we analyse the laterality, the relation between correct responses and reaction times, the direction patterns for wrong responses and we perform an analysis on the Stimulus-Response Compatibility and on the training effect.

Index Terms—joysticks, vibrotactile stimuli, attractive / repulsive prompt, haptics, reaction time.

1 INTRODUCTION

JOYSTICKS are often used as input devices to remotely operate a machine or a robot in master/slave configuration. Even though they have been conceived in the 60s, they can still find application in many different fields: excavators, cranes, forklifts, electric-powered wheelchairs, robot telemanipulation and micromanipulation. Concerning robot telemanipulation, joysticks are employed in considerable tasks such as, for example, robots for surgery or robotic systems for missions in orbit or for planetary exploration.

Joysticks large diffusion and flexibility of applications are due to the fact that they are reliable, ergonomic (operator's elbows lay on armrests), cost-affordable, ideal for rugged applications and, to certain extension, intuitive to operate. In fact, if the manipulator is controlled in such a way that there is a direct correspondence between each joystick Degree of Freedom (DoF) and each manipulator joint position or velocity, the mapping between the DoFs of the slave manipulator and the DoFs of the joysticks are counter-intuitive. This is because the inverse kinematic calculation, from the DoFs of the manipulator to the DoFs of the joystick, is mentally demanded [1]. Because of the counter-intuitive and demanding cognitive mapping processes, candidate users of joysticks require long-time training sessions to acquire the skills needed to operate in a safe and efficient way. Training can be performed on the field but it is an approach that raises several safety and cost issues. For these reasons in the last decades several training simulators, especially in the field of heavy equipment (mostly excavators [2] [3] and cranes [4] [5]), have been developed. The training is usually based on trial-and-error sessions where a skill instructor supervises and gives verbal instructions. At the present time, vibrotactile stimulations have never been provided during joysticks motion training in order to prompt the subject.

On the other hand, vibrotactile feedback systems have been applied in several different fields, for example in sports, to improve athletes performances; in rehabilitation, to recover lost motor functions as quickly and permanently as possible; in navigation and orientation, in order to reduce the workload of visual and auditory systems [6]. In sports, tactile displays applications can be found in soccer [7], skating and cycling [7], dancing [7] [8], rowing [7] [9] and snowboarding [10]. A vibrotactile feedback system, combined with motion capture, has been developed also in the field of music in order to support the teaching of good posture and bowing technique to novice violin players with important results [11]. Several studies have shown the efficacy of vibrotactile feedback also during stroke rehabilitation [12] [13] [14] and gait retraining [15]. Vibrotactile displays can also support navigation and orientation while walking [16] [17] [18], driving [19] and operating in a helicopter cockpit [20]. Furthermore, vibrotactile stimulations to the torso have been used to indicate directions in a virtual environment in combination with joystick manipulation [21].

Two possibilities for providing instructional stimulations have been studied: attractive, for which a subject is instructed to move toward the vibration, and repulsive, for which a subject is instructed to move in the opposite direction with respect to the vibration felt.

Attractive stimulation has been applied during walking in pedestrian guidance [16] [17] [18], driving [19] and flying

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[20]. On the other side, repulsive stimulations have been used in the development of a balance prosthesis using vibrotactile feedback to indicate body movements away from a stable position [22]. Other studies based on repulsive cues have been carried out for postural control recovery from multi-axis discrete perturbations [23], real-time biofeedback during balance training [24] and trunk sway during gait tasks [25]. Furthermore, other studies have shown that, in the absence of instruction, random vibrotactile stimulation over the internal obliques muscles and erector spine muscle induces small tilt deviations on the order of 1.0° toward the stimulation [26] [27] [28]. Moreover, in [29], a preferred direction of intuitive response to vibrations on different body location has not been found.

Up to now, only few studies have compared the effects of attractive versus repulsive instructional cues. In the study of torso vibrotactile feedback on balance performance participants performed better when using repulsive cues [30]. Similar results have been obtained in the examination of anterior-posterior trunk movements [31]. In the experiments on an arm guidance system for use in rehabilitation, no strong preference or performances differences between attractive and repulsive tactile feedback was found [32]. In contrast, the attractive mode proved to be more intuitive for initiating left and right wrist rotations [33]; in the wrist guidance in 2-D space, the "pull" approach (attractive) allows participants to perform better with respect to the "push" mapping (repulsive) [34]. Furthermore, in a recent study on the training in divergent (repulsive) and convergent (attractive) force field during teleoperation with a robot-assisted surgical system, a better performance of the repulsive field was highlighted throughout the training, even though no significant differences were found at the end of the experiments [35].

No studies on the effects of attractive versus repulsive vibrotactile stimulation for prompting joysticks motion have been performed until now. The aim of this work is to establish whether an attractive stimulation gives better results than a repulsive one in a joysticks training session, in terms of correct responses and reaction times during a test. At the same time, we investigate whether a vibration stimulating the back of the hand is more efficient than a vibration provided by the joystick and stimulating the palm of the hand. This paper is an extended version of a preliminary work presented at IEEE World Haptics Conference 2017 [36]. It is organized as follows: firstly, we provide a detailed exposition of our methods and experimental set-up (Section 2). Then, results are analysed, taking into account correct responses and reaction times as main performance metrics (Section 3). Finally, a forward-looking discussion (Section 4) and the conclusions of this work (Section 5) are presented.

2 METHODS

2.1 Participants

In this study, participants were recruited among the population of students and professors of the University of Trieste. A total of 53 people (40 males, 13 females) participated, ranging in age from 20 to 45 years with mean of 25.1 and standard deviation of 4.1. All participants have been subjected to the Handedness Questionnaire [37] in order to calculate their Laterality Index (LI); fifty of them were mainly right-handed, the other three left-handed.

The right hand span of each subject was measured before the experiment and a value of $20.9 \pm 1.8\ cm$ was found. Six participants had a previous practice with flight simulator joysticks, five of them had experience in the driving of an excavator by means of joysticks and forty three subjects had practice with video game console before. None of the subjects involved in the experiment had a mobility disorder of upper limbs, twenty six of them were wearing glasses. The University of Trieste Ethics Committee approved the experimental protocol and each participant gave informed consent prior to starting the tests.

2.2 Experiment apparatus

The experimental set-up is composed of two joysticks, two gloves and a data acquisition device connected to a computer. Each joystick (Fig. 1(a)) and glove (Fig. 1(b)) is equipped with four vibrating disk motors to induce the vibrotactile stimuli. The vibrating motors are simple coin electric actuators by Precision Microdrives^{TM} with a diameter of $10.0\ mm$ and a thickness of $3.0\ mm$. They operate at a rated voltage of $3\ V$ and provide a vibe force with an amplitude of almost $1\ g$ and a frequency of $200\ Hz$, drawing less than $90\ mA$. They have a typical rise time of $92\ ms$ and a stop time of $116\ ms$. The four vibrating motors are placed on the gloves in a cross configuration.

(a)

(b)

Fig. 1: Experimental apparatus: joysticks (a) and gloves (b) equipped with vibrating motors.

For the experiment two video game joysticks by Speedlink, model WASP SL-6612, are used. Inside each joystick two resistive potentiometers are present, which are

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able to detect the motion of the sticks in the four directions and send four analogue signals to the data acquisition device. The original stick has been replaced with a handle in teflon, which incorporates a foam rubber ring on which the four vibrating motors are placed, in order to avoid the transmission of the vibration to the whole stick during the tests. All vibrating motors input wires are contained in the sticks and are connected, by means of a DE-9 connector, to the power circuit.

2.3 Data acquisition set-up

The data recorded by the potentiometers are logged into a specific portable acquisition device (MyRIO-1900 by National Instruments). For this purpose a real-time control system has been developed in LabVIEW™ environment. The data acquisition device is also used to control the activation of the vibrating motors during tests, switching on and off the 3 V power by means of digital outputs. During each test the four analogue signals from the potentiometers and the boolean value (on/off) of each vibrating motor are acquired at a sampling rate of 1 KHz and saved in an output file. MyRIO is connected to a computer by means of a USB cable. On the PC runs a graphical user interface, thanks to which it is possible for the experimenter to select the test to perform, start the experiment, abort it and control its correct execution.

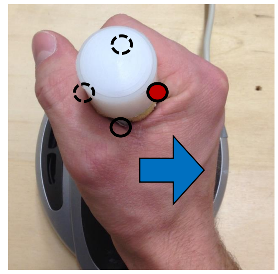
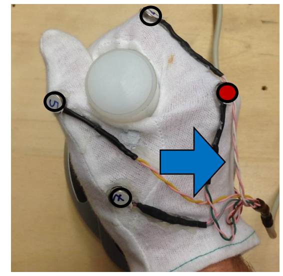
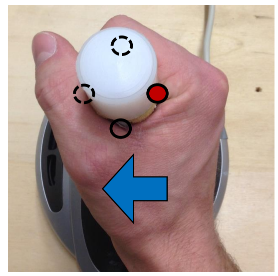
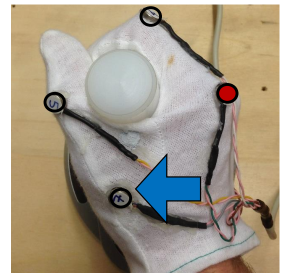
2.4 Test protocol

All participants completed four different vibrotactile instructional cues, two provided from the vibrating motors placed on the joysticks and stimulating the palm of hands in attractive and repulsive mode, two provided from the gloves vibrating motors and stimulating the back of hands in both modalities. For the sake of simplicity, these four different tests have been called Attractive Joystick, Repulsive Joystick, Attractive Glove and Repulsive Glove. In Tab.1 an example for each of the four tests is reported.

Each of the four tests is composed by 16 vibrotactile stimulations provided in a different random order: two for each main direction (Forward, Backward, Right and Left) of the two hands. Each stimulation consists of a 200 ms single vibration: the attractive mode is intended to induce the motion of the joystick in the direction of the delivered vibration, whereas the repulsive mode should induce the motion of the joystick in the opposite direction to the one from which the vibration comes from. Each stimulus was delivered at only one hand at a time. The four tests are completed by participants in random order by alternating the attractive and the repulsive modalities, so as to avoid that the results were distorted by the progressive learning of the subjects.

Before the start of the experiment, subjects were informed about the tests and they were asked about personal information for statistical purposes (age, gender, right hand span length, previous experience with flight simulators, excavators and video game console controlled by means of joysticks, whether upper limbs disorders were present and glasses worn) and they were subjected to Laterality Index questionnaire. Then they were instructed to sit in front of the experiment set-up, to handle the joysticks with both hands

TABLE 1: Examples of the four different tests. The red dot indicates the stimulus whereas the arrow the prompted direction.

	Joystick	Glove
Attractive		
Repulsive		

(wearing gloves or not depending from the test) and listen which test they were going to attend. After that they were instructed to move the joystick related to the stimulated hand in the direction of the vibration (or in the opposite one) as soon as they feel the stimulus. After the movement, they should bring back the joystick in its central position. The vibrational stimulations were dispensed every three seconds, lasting a total of 48 s for each test.

2.5 Data analysis

Data acquired during the experiments were elaborated in order to find the reaction times and the number of correct movements during each test. A dedicated software for data analysis was implemented in Matlab™ environment. Data elaboration software was able to import results from output files for each of the four tests. Values acquired from each potentiometer ranged between -1 and 1, corresponding to the minimum and the maximum voltage value. In Fig. 2(a) a graphical representation of an Attractive Glove test is reported. The four graphs show the vibration prompts and the motion of both right and left joystick over time, in the four directions.

The reaction time was computed as the time elapsed between the beginning of the stimulus and the time at which one of the two joysticks potentiometers reached 75% of its range. The threshold was selected before the start of experiments by analysing the results of pilot tests. Such a value avoided recording unintentional movements while it triggered the response before the end of the workspace was reached. In attractive conditions, the response was considered correct if the potentiometer that first passed the threshold was in the direction of the vibration, whereas in repulsive conditions it was in the opposite direction. Fig. 2(b) and 2(c) depict the time line of an attractive and a repulsive trial respectively.

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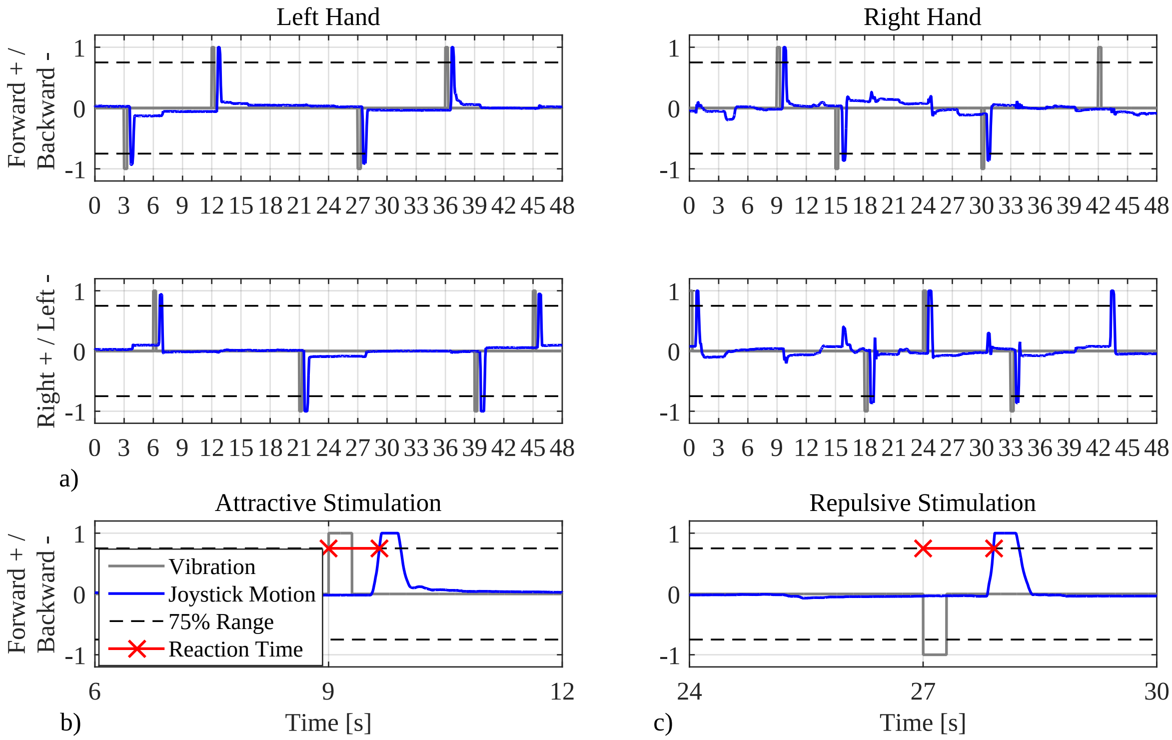


Fig. 2: (a) Graphical representation of an Attractive Glove test: the four graphs indicate the responses over time of the right and left hands in the four directions. (b) Zoom on a single Attractive stimulation. (c) Zoom on a single Repulsive prompt.

A statistical analysis has been provided for the outcome evaluation. For each set of numerical continuous variables, the normality has been verified by means of Kolmogorov-Smirnov test. The eventual correlation between normal continuous variables and stimulation patterns has been studied, in case of variances homogeneity, by means of 2-way repeated measures ANOVA test. The eventual correlation between non-normal continuous variables and vibration patterns has been evaluated by means of Wilcoxon two-sample paired signed-rank test. To evaluate statistical differences between two related units on a continuous outcome that is normally distributed the paired-sample *t*-test has been adopted. To test for consistent differences between pairs of observations the Bonferroni corrected sign test has been applied.

3 Results

3.1 Correct responses

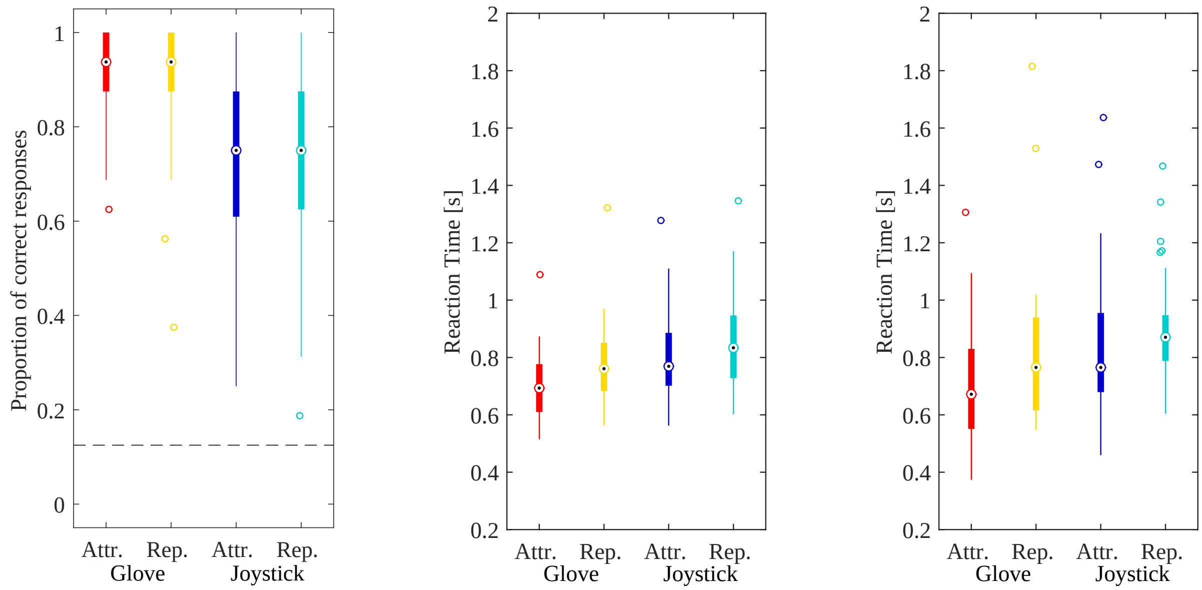
The proportion of correct responses is not distributed normally (K-S test $p < 0.001$). Fig. 3(a) summarises the responses obtained in the four conditions. Responses were more frequently made in the correct direction when tactile cues were delivered using the glove (Wilcoxon two-sample paired signed-rank test $N = 53$; attractive $Z = -5.13$, $p < 0.001$; repulsive $Z = -5.65$, $p < 0.001$).

There was no coherent difference in the number of correct responses due to attractive/repulsive task demand (Wilcoxon two-sample paired signed-rank test $N = 53$; glove $Z = -0.33$, $p = 0.75$; joystick $Z = -0.18$, $p = 0.85$).

3.2 Reaction times

Reaction times are found to be normally distributed across participants (K-S test $p = 0.180$, $p = 0.065$ for right and wrong responses). Fig.s 3(b) and 3(c) summarise the reaction times for correct and wrong responses in the four conditions, whereas Tab. 2 reports mean and standard deviation values in milliseconds. Participants responded faster when the stimulations was provided by gloves rather than from joysticks (factor gloves/joysticks of a 2-way repeated measures ANOVA on average RT: $F(52, 1) = 77.7$, $p < 0.001$, $\eta_p = 59.9$). Moreover, correct responses were faster in the attractive modality (factor attractive/repulsive of the 2-way repeated measures ANOVA: $F(52, 1) = 28.0$, $p < 0.001$, $\eta_p = 35.0$). The interaction between the two factors is not significant ($F(52, 1) = 1.3$, $p = 0.25$, $\eta_p = 2.5$).

Reaction times for incorrect responses is usually higher than for correct responses (paired-sample *t*-test on average reaction time across conditions $t(50) = -2.7$, $p = 0.0082$). Interestingly, the difference is only driven by the repulsive conditions (Bonferroni corrected sign test on the RT difference for each condition: Attractive Glove $p = 0.67$, Repulsive Glove $p = 0.022$, Attractive Joystick $p > 0.99$, Repulsive Joystick $p = 0.050$). Similar to the correct responses, erroneous responses were faster with gloves (factor glove/joystick of a 2-way repeated measures ANOVA on average RT: $F(52, 1) = 27.9$, $p < 0.001$, $\eta_p = 34.9$) and in the attractive modality (factor attractive/repulsive of the 2-way repeated measures ANOVA: $F(52, 1) = 10.4$, $p = 0.0022$, $\eta_p = 16.7$), while the interaction between the two factors is not significant ($F(52, 1) = 0.09$, $p = 0.77$, $\eta_p = 0.01$). Furthermore, in Fig. 4 the reaction times as function of response direction for the four different tests



(a) Percentual number of right responses.

(b) Mean reaction time of right responses.

(c) Mean reaction time of wrong responses.

Fig. 3: Box plot representation of experimental results. The central mark indicates the median, the bottom and top of each box represent the first and third quartiles, the whiskers extend to the most extreme data points not considered outliers.

TABLE 2: Mean and St. Deviation of correct and wrong responses reaction times [ms].

Test	Correct responses Mean	Correct responses St. Dev.	Wrong responses Mean	Wrong responses St. Dev.
Attractive Glove	697	105	702	203
Repulsive Glove	773	130	810	271
Attractive Joystick	796	135	833	227
Repulsive Joystick	847	149	890	170

are shown. In the Figure, each couple of polar diagrams corresponds to the workspace of left and right joysticks; each symbol represents the response to a stimulus. For each response, its radial coordinate is equal to the reaction time. The colours in the legend indicates the direction of the vibration: Forward (90 degrees), Backwards (270), Rightwards (0), Leftward (180).

3.3 Laterality

37 out of the 53 participants have more correct responses with their right hand (sign test on the difference of overall correct responses with the two hands $p < 0.001$). Further analysis indicates that the effect is due exclusively to the Repulsive Joystick condition, where the number of participants with higher correct responses with stimuli delivered on the right is 38 out of 53 (Bonferroni corrected sign test for each condition: Attr. Glove $p > .99$, Rep. Glove $p > .99$, Attr. Joystick $p = 0.078$, Rep. Joystick $p < 0.001$).

Reaction times and response correctness were compared between the left and right hand for the 50 participants that exhibited positive values of Laterality Index ($LI > 0$ for right-handed subjects, $LI < 0$ for left handed). This analysis indicates no significant differences across the four stimulation conditions, except for the Repulsive Joystick. In this condition, the number of correct responses (Bonferroni corrected sign test $p = 0.004$), the number of wrong ones ($p = 0.036$), and the mean reaction time of wrong movements ($p = 0.049$) indicate better performance for responses given with the right hand.

3.4 Correct responses versus reaction time

In Fig. 5 the correct responses number for each participant related to the mean reaction time in the four different tests is reported together with one interpolating straight line per condition. The graph shows that participants with a high number of correct responses reacted also faster to the stimuli. This relationship may be due to between-subject variability, i.e. skilled subjects are more sensitive to vibrotactile stimuli, causing less errors. By considering interpolating lines, no information about the comparison between attractive and repulsive modalities can be obtained. The interpolating lines related to Glove tests for both the attractive and repulsive conditions are higher than the associated Joystick conditions, suggesting that vibrotactile stimuli by gloves led to better performance compared to stimulations provided by joysticks.

Furthermore, a linear mixed-effects analysis has been performed in Matlab™ in order to reveal how the linear relationship between correct responses and reaction time changes with the joystick/glove as a factor. In Tab. 3 the proportion of correct responses as function of eight samples of reaction time is reported for the different conditions. From the Table it can easily be seen that the stimulation coming from the joystick requires approximately 300 ms more, on average, to achieve the same performance as the glove condition, both for attractive and repulsive prompts.

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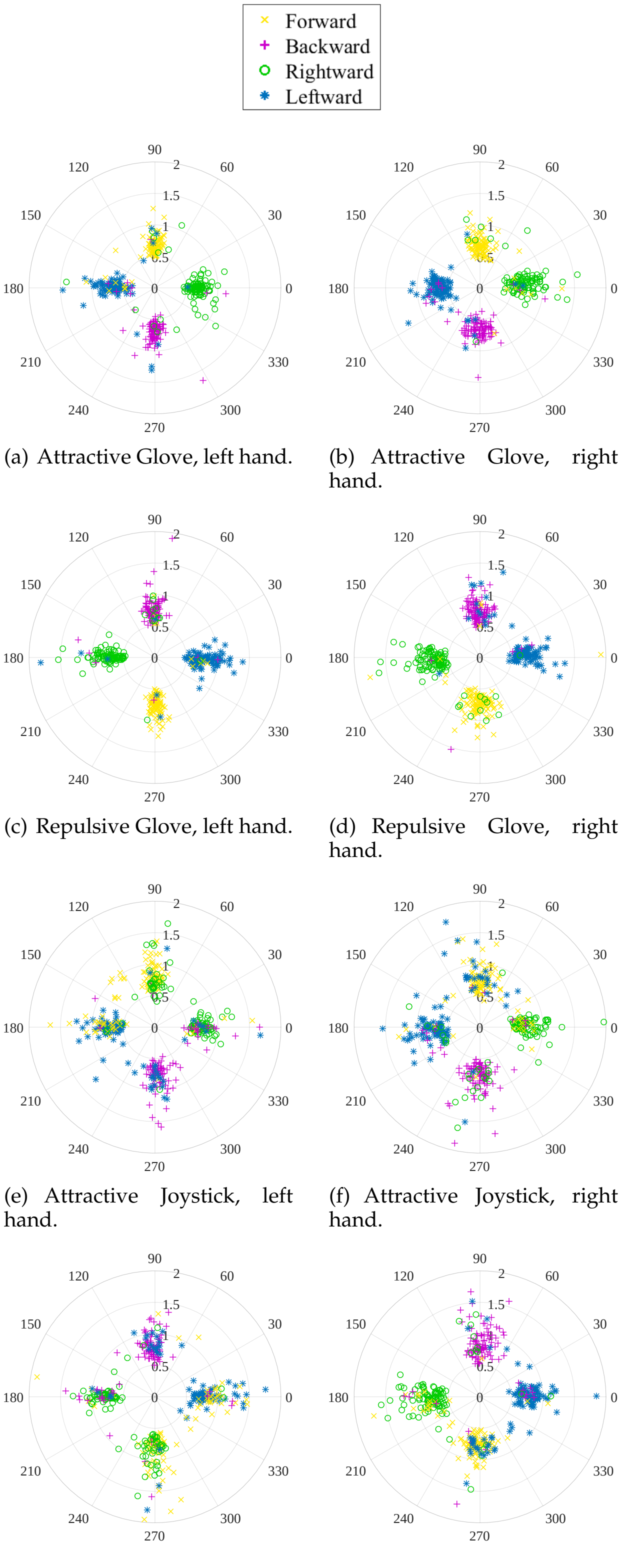

(a) Attractive Glove, left hand. (b) Attractive Glove, right hand.

(c) Repulsive Glove, left hand. (d) Repulsive Glove, right hand.

(e) Attractive Joystick, left hand. (f) Attractive Joystick, right hand.

(g) Repulsive Joystick, left hand. (h) Repulsive Joystick, right hand.

Fig. 4: Reaction times in function of response direction for the four different tests. Each couple of polar diagrams corresponds to the workspace of left and right joysticks; each symbol represents the response to a stimulus. For each response, its radial coordinate is equal to the reaction time.

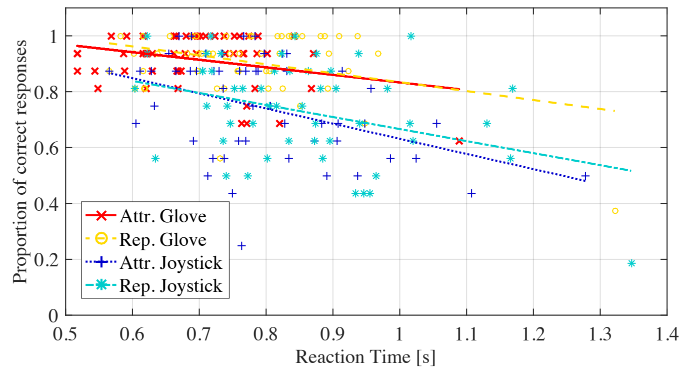

Fig. 5: Relation between correct responses and reaction times, together with one interpolating straight line per test.

TABLE 3: Proportion of correct responses as function of reaction time [ms] (predicted by means of linear mixed-effects analysis) for the four conditions.

RT [ms]	Glove Attractive [%]	Glove Repulsive [%]	Joystick Attractive [%]	Joystick Repulsive [%]
600	95.1	97.3	83.0	84.1
700	90.9	93.1	78.8	79.9
800	86.7	88.9	74.6	75.7
900	82.5	84.7	70.4	71.5
1000	78.3	80.5	66.2	67.3
1100	74.1	76.3	62.0	63.1
1200	69.9	72.1	57.8	58.9
1300	65.7	67.9	53.6	54.7

3.5 Direction patterns for wrong responses

We investigated whether the direction towards which wrong responses have been given shows a consistent pattern. Figure 6 shows the direction of wrong responses for each stimulus direction, in attractive and repulsive stimulation condition, for the left and right joysticks. Interesting trends can be observed. In the Attractive Glove, a forward vibration produces error responses towards the left for the left joystick, but right for the right joystick. In the other directions of stimulation, errors occur mainly 90 degrees from the correct direction. This trend is present also in Attractive Joystick condition, where the number of errors is higher overall. Wrong responses in the repulsive stimulation conditions occur instead in both directions adjacent to the correct one and only rarely in the opposite direction. This should indicate that only in few cases subjects get confused with the repulsive stimulation and move the joystick toward the vibration rather than in the opposite direction.

3.6 Stimulus-Response Compatibility

The experimental setup to test dual-joystick directional responses to vibrotactile stimuli presented in this work can be also considered as a Stimulus-Response Compatibility (SRC) test [38] [39] [40]. For this purpose, it is possible to take into account the accuracy and correct responses reaction times in the different directions and to analyse the compatibility or incompatibility between stimuli and responses in the four different conditions. In particular, some might think that a stimulus on the back of the hand

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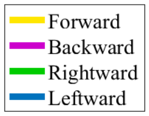
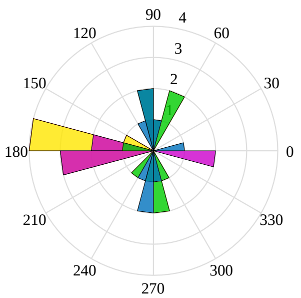
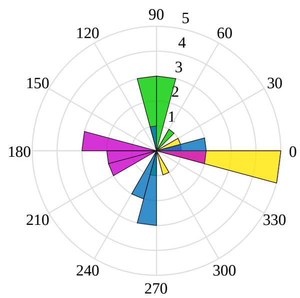
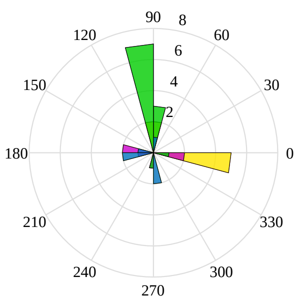




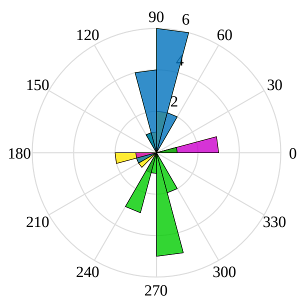
(a) Attractive Glove, left hand.



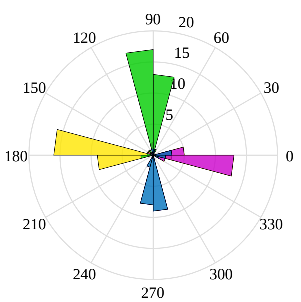
(b) Attractive Glove, right hand.



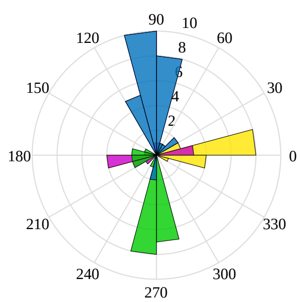
(c) Repulsive Glove, left hand.



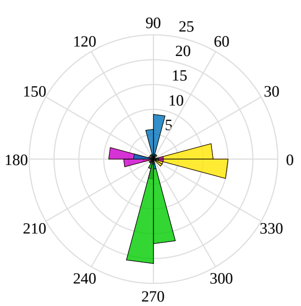
(d) Repulsive Glove, right hand.



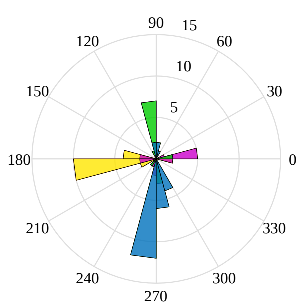
(e) Attractive Joystick, left hand.



(f) Attractive Joystick, right hand.



(g) Repulsive Joystick, left hand.



(h) Repulsive Joystick, right hand.

Fig. 6: Amount of wrong responses with respect to the response directions for the four different tests. Each couple of polar diagrams corresponds to the workspace of left and right joysticks. The frequency of each polar histogram is reported on the radius.

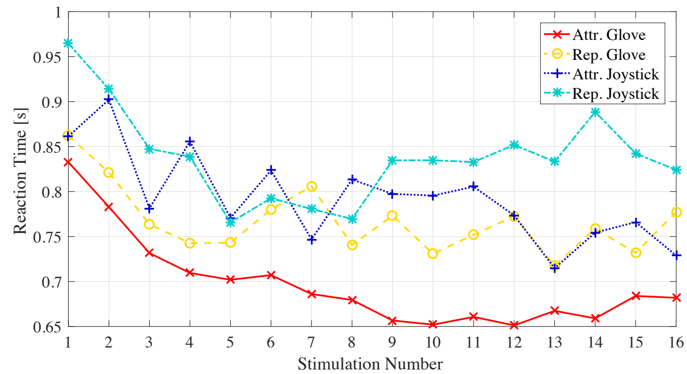


Fig. 7: Mean reaction times of all participants for the four different conditions throughout the 16 stimulations.

could be more comfortable rather than a vibration perceived on the palm of the hand. In which condition the subjects will respond faster? In Table 4 the accuracy, as well as mean and standard deviation reaction times, are grouped together in order to better highlight the differences in front, back, left and right stimulation of the subjects hands in the different condition and to understand when a compatible stimulus-response relationship occurs. In particular, by considering responses given with the right hand, subjects performed better with vertical (i.e. front/back) rather than horizontal (i.e. left/right) in the Repulsive Glove and in both of the joystick conditions.

3.7 Training effect

Finally, we analysed the trend of correct responses reaction times for the four different conditions throughout the experiments. In Fig. 7 the mean reaction time for each of the 16 stimulation is reported and interesting trends emerge. In particular, it can be seen that in the Attractive Glove test reaction times quickly decrease from values higher than 0.8 s to below 0.7 s after 7 stimulations. This is due to the training effect and to the progressive adaptation of the subject to the stimuli. Furthermore, it can be noticed that Attractive Glove reaction times are lower than those of other conditions during the whole experiment. This fact confirms the better performance of attractive modality with respect to the repulsive one and of glove stimulation rather than the joystick one. By considering the other conditions, a training effect is present in the Repulsive Glove and in the Attractive Joystick as well. No interesting considerations emerge from the Repulsive Joystick condition, which can be considered the most difficult one.

In conclusion, we investigated if reaction times depend on whether the previous stimulation was the other hand or not. In order to perform this, in Tab. 5 the mean and standard deviation of correct responses reaction times are reported for the four conditions by grouping them together in four columns, according to the stimulated hand, and to the previous one. In the Attractive Glove test responses are faster with the right hand when the previous stimulated hand was also the right one; in the Repulsive Glove reaction times are faster with the left hand when the previous was the same one. In Joystick conditions responses are faster when the previous hand was the opposite one.

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TABLE 4: Accuracy [%] and correct responses reaction times [ms] in the different directions.

			Left Hand				Right Hand			
			Front	Back	Left	Right	Front	Back	Left	Right
Attr. Glove	[%]		92.5	90.6	91.5	89.6	93.4	90.6	92.5	92.5
	$[ms]$	Mean	685	713	669	707	697	684	668	741
		St. Dev.	129	161	172	132	196	133	135	213
Rep. Glove	[%]		91.5	94.3	91.5	86.8	91.5	95.3	86.8	87.7
	$[ms]$	Mean	758	761	802	752	767	755	748	792
		St. Dev.	156	178	191	190	155	149	170	214
Attr. Joystick	[%]		68.9	74.5	69.8	65.1	81.1	87.7	72.6	77.4
	$[ms]$	Mean	844	784	738	788	795	825	785	777
		St. Dev.	175	212	179	262	294	256	202	215
Rep. Joystick	[%]		58.5	74.5	71.7	55.7	82.1	84.9	74.5	85.6
	$[ms]$	Mean	903	819	861	800	798	873	818	838
		St. Dev.	296	168	280	155	207	231	197	224

TABLE 5: Mean and St. Dev. of correct responses reaction times [ms] grouped together on the basis of the actual and previous stimulated hand.

Previous hand		Left		Right	
Stimulated hand		Left	Right	Left	Right
Attr. Glove	Mean	695	684	694	669
	St. Dev.	166	156	136	114
Rep. Glove	Mean	752	762	756	779
	St. Dev.	152	158	179	203
Attr. Joystick	Mean	809	788	783	785
	St. Dev.	303	233	162	221
Rep. Joystick	Mean	864	828	816	838
	St. Dev.	227	201	205	235

4 Discussion

The results presented in this paper suggest that an efficient way to assist an operator in a dual-joystick directional guidance consists in providing haptic prompts delivered on the back of the hands in attractive mode. Indeed, reaction times, for Attractive Glove stimulation, ranges from about 0.5 to 0.9 seconds and they are lower than for other stimulation cases. In this context, stimulations from gloves revealed to be more efficient with respect to the ones from joysticks because vibrating motors placed on gloves, on the back of the hand, are further apart from each other and the stimulated point on the skin is better identifiable.

On the contrary, vibrating motors placed on the joysticks are probably too close to each other and the direction of the stimulus on the palm of the hand could not be adequately felt. Furthermore, the effects of stimuli on the bony parts of the hand as well as the effects of grasping the joystick could also have played a role in the tests. However, gloves should be correctly worn and the vibrating disk should be into contact with the skin. In addiction, a non correct grasp of the joystick could result in a non perfect alignment between the joysticks main directions and the vibrating actuators layout, leading to motions in direction not perfectly correct.

In future, we plan to further investigate vibrotactile stimulation in the training of an operator using joysticks. More vibration schemes could be tested by varying the duration of the stimulus and the actuators location. Furthermore, different types of actuators (e.g. voice coil motors) could be tested in order to improve the localisation ability. In future, a practical training protocol could be developed on the basis of this research results.

5 Conclusion

In this paper we presented the effects of vibrotactile stimulation during joysticks motion training. A comparison between attractive and repulsive stimulation has been conducted. Furthermore, we investigate whether a stimulation on the back of the hands is more efficient than the one provided to the palm of the hands. Fifty-three people participated in the experiment. Results showed that attractive stimulation is significantly more efficient in terms of reaction times with respect to the repulsive modality. Secondly, we found that, by stimulating the back of the hands with gloves, the subjects performed better in terms of both reaction times and number of correct responses, with respect to a stimulation on the palms, provided by joysticks. Finally, we analysed the laterality, the relation between correct responses and reaction times and the direction patterns for wrong responses. Along the same lines, we performed an analysis on the Stimulus-Response Compatibility and on the training effect, which will be further studied in future developments of this work.

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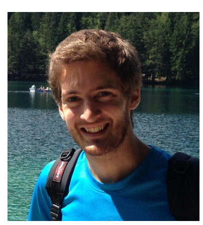

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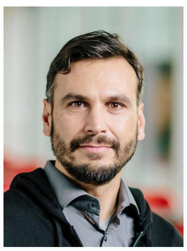

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