Haptic Expression and Perception of Spontaneous Stress

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Abstract—Previous studies about kinesthetic expressions of emotions are mainly based on acted expressions of emotions, which can be quite different from spontaneous expressions. This paper describes a study involving a stress induction procedure and stress perception through haptic expressions with $\mathrm{N}_{\mathrm{total}}$ = 41 young men (aged $19-37$), all right-handed. We designed a game application to collect spontaneous expressions of stress. This application involved haptic interactions and a stressful event. We observed changes in the haptic behaviors of the participants over different phases: before, during and after the stress induction. In the next step, we investigated how the collected haptic behaviors (both kinematic and force components) were haptically perceived by the other participants. The results suggest the ability of kinesthetic expressions to communicate a spontaneous stress from one person to another.

Index Terms—Haptic expression, haptic perception, spontaneous, stress.

1 Introduction

Emotions play a key role in human communication. The expression of emotions uses and combines various non-verbal modalities (visual, auditory, etc.). However, research up to now has mainly focused on the study of facial expressions [1], gestural expressions [2], and speech [3]. Recent work has shown that the haptic modality is efficient at conveying some affective states by means of specific touch patterns [4]. Researchers have highlighted the role of the tactile channel to support social interactions and to form and maintain social bonds [5]. With the development of Human–Machine Interfaces and communication technologies, haptic devices for remote and mediated communications have been proposed [6], [7]. The current study raises two issues. The first issue concerns the limits of existing haptic devices in reproducing realistic tactile expressions of emotions. The second issue concerns the identification of haptic models, i.e., tactile and kinesthetic patterns and physical features, to effectively express different emotions. While research in the field of haptic stimulation and rendering technologies is promising for affective and social communication, the identification of efficient haptic models is still an issue.

The identification of affective models is often based on the analysis of a corpus of affective expressions (facial, gestural, etc.). Such a corpus contains expressions of acted emotions where the subjects are explicitly asked to express an emotion. However, recent work has shown that spontaneous expressions of emotions display differences with acted expressions of emotions [8]. Spontaneous expressions of emotions include relevant physical features to express and effectively recognize those emotions. [9] have even said, about their work on the speech modality: "Acted emotional speech is not felt, and is perceived more strongly than real emotional speech. This sheds doubt on the use of actors for emotion research, especially if the goal is to study real emotions."

Surprisingly, current research in affective haptics has focused only on acted affective states. Yet the study of the haptic expressions of spontaneous affective states is relevant to several fields, for instance, to the automatic identification of affective states (joy, stress, etc.) from tactile and kinesthetic cues of emotional states in real contexts, or to the efficient induction of some emotional states in the context of computer-mediated communication (video games, films, etc.).

This paper considers haptic expressions of a spontaneous stress. It aims to identify the relevant haptic cues indicating the presence of stress during a video game task, and to improve our knowledges on haptic expressions of stress. Stress is a pattern of negative physiological states and psychological responses occurring in situations where individuals perceive threats to their well-being, which they may be unable to meet [10]. It occurs when a situation undermines a person's sense of control [11]. The study and the identification of its related emotional states is important for several reasons. First, stress is recurrent in everyday life, for example, during exams or job interviews. Thus, it plays a key role in human–human communications [12]. Second, stress is linked to some health problems, such as depression and cardiovascular diseases [13]. Therefore, stress detection could help to prevent diseases linked to high amounts of stress. Stress might also be a cue for detecting emotions such as irritation or anxiety, which are hard to detect with facial expressions or prosody [14]. Other fields would be for mediated communication and asynchronous messaging extended to haptics.

We propose the study of both the expression and perception of stress through the haptic modality. In the first step of our study, we investigated how people express stress with the haptic modality. The study focuses on the stress expressed in the context of a video game. Based on an experimental protocol designed specifically for this experiment, we collected a corpus of spontaneous haptic

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Manuscript received X, X; revised X, X.

expressions of stress. Then the corpus was statistically analyzed in order to identify the specific haptic cues of stress, more specifically, kinesthetic and tactile features. Statistical analyzes highlighted depending on the presence or absence of stress induction, differences in mean speed, jerkiness and pressure exerted.

In the second step of the study, we investigated whether people perceive stress in haptic expressions collected after stress induction. The collected haptic expressions were presented one by one to subjects. They were asked to detect the changes of features of the kinematic and force components, and to identify the expressions presenting stress. The analysis highlighted that the differences in mean speed and pressure that were statistically observed were perceptible by users. These users were also able to determine which expressions were collected during stress.

The rest of this paper is structured as follows. The next section presents the background related to the different issues of this research. Section 3 presents our study to collect haptic expressions of stress and the statistical analysis of its haptic features (kinematic and force components). Sections 4 and 5 present our studies that investigated how people perceive stress in haptic expressions. Both the kinematic and force components were studied separately due to technical constraints. Finally, Sections 6 and 7 discuss the results and conclude the paper.

2 Background

2.1 Emotions and Haptics

Research in the role of haptics in conveying and communicating emotions is relatively recent. [4], [15] observed that haptic stimulation can be used to communicate at least six different types of emotions: anger, fear, disgust, love, gratitude, and sympathy. The authors observed that the recognition rates of emotions expressed via the haptic modality (i.e., using a real physical contact) between two people are comparable to those obtained with facial expressions or speech. That study identified specific patterns and haptic features of interpersonal contact used by participants to communicate different emotions. Other research has highlighted that a light touch experienced as pleasant is an important component of social interactions and could play a central role in forming and maintaining social bonds [16]. Those authors conducted a series of studies establishing the existence of slow conducting, unmyelinated CT-fibers in the hairy skin that have the potential to elicit pleasant subjective perceptions. [17] studied the physical features of affective haptic expressions. They designed an experimental platform to record and analyze affective haptic expressions. Subjects were asked to express a series of emotions by shaking a haptic device, a joystick with two degrees of freedom (2DoF). Then the recorded haptic expressions were presented to other subjects to assess the recognition of affective expressions. The results highlighted some haptic patterns and physical features expressing the investigated emotions, for instance, a swinging gesture to express joy and a jerky movement to express anger. These results were in agreement with the work of [18].

[19] proposed a method, based on cluster analysis, allowing the analysis and the identification of the relevant features of affective haptic expressions. That paper showed that people express emotions with the haptic channel in different ways. For example, they highlighted two different kinds of haptic expression of disgust. [20] proposed a probabilistic Markovian model to recognize affective haptic expressions. Beyond the simultaneous management of several features, this approach enables the processing of the dynamic features of haptic expressions, such as the size of the interaction surface and the applied force.

Several studies have used haptic devices to communicate emotions, for instance, for interaction with virtual characters or for communication with remote partners. [21] designed a virtual agent capable of physically touching users in synchrony with other nonverbal channels of communication. The agent is composed of an animated human-like face displayed on a monitor fixed on the top of a human mannequin. Touch behaviors were conveyed by an air bladder's squeezing the user's hand. The agent was designed to express empathy with users in distress within healthcare applications. The authors showed that when touch is used in the context of an empathic, comforting interaction, it can lead to better perceptions of the relationship with the agent.

Based on human–animal interaction studies, [7] developed "Haptic Creature," a robot that mimics a small pet interacting with users through touch. The analyses of the physical properties of the touch interaction (points of contact, duration, intensity, etc.) enabled them to identify touch patterns (stroking, tickling, etc.).

There have also been several studies investigating the use of haptics for remote communication and telepresence. For example, [22] presented the "CheekTouch" device, which provides an intimate tactile feedback via a mobile phone on the user's cheek. The presented affective interaction technique combines tactile feedback, delivered on the cheek, and multi-finger input, while speaking on the mobile phone. The authors designed six affective touch behaviors (pinching, stroking, patting, slapping, kissing, and tickling). [23] developed a synchronous haptic teleconferencing platform, called "HugMe," that enables exchanging physical stimuli to convey affection and intimacy. The haptic stimulation is provided by a suit that contains embedded vibrotactile actuators to simulate tactile mechanoreceptors. An active user can see and touch a remote passive user, who is captured in 2.5D, using a 3DoF force feedback.

2.2 Collecting Expressions of Spontaneous Emotions

There are several approaches to collecting expressions of emotions [24]. One approach concerns the study of the expressions of acted emotions. Subjects or actors are instructed to express an emotion using more or less directed instructions. The recording of expressions is rather simple, for instance, by asking the subjects to look at a camera when acting or using a microphone when speaking. Regarding haptic expressions, the hardware set-up is more complex. Recording haptic behavior requires a physical contact between the force and tactile sensors and the user's body (hand, forearm, etc.). For instance, sensors can be integrated into a mechanical device handled by the user [17].

Another approach to collecting expressions involves the study of spontaneous emotions. Emotional behavior can be observed in natural settings, for instance, in everyday life. The study of this type of emotion introduces other constraints related to the use of tactile and force sensors. In fact, a physical contact with sensors may be perceived as too intrusive, thus limiting natural behaviors [25].

An alternative way to collect spontaneous expressions of emotions is to induce emotions. This approach allows a better control of the induced emotion and a way to record the corresponding expressions. The main drawback of this approach is that participants are aware that they are in an experimental setting, which may inhibit their natural behavior [24]. Thus, the main challenge of this approach is to find the most efficient method for inducing spontaneous expressions of emotions. There are three common methods of inducing emotions:

- *Media supports.* A common way to induce emotions is to use various media supports, such as visual supports (e.g. International Affective Picture System [26]) and audio supports (e.g. International Affective Digital Sounds [27]). Videos are also very efficient at inducing emotions and are able to catch the attention of participants (FilmStim [28]). Using media to induce emotions nevertheless has some drawbacks. For instance, the induction of the emotion might not be uniform throughout the media. The induction may also elicit blends of several emotions [29].
- *Social interactions.* A second way to induce emotions involves social interactions. The social component of emotions is known to be quite important [30]. This method requires the simultaneous presence of at least two people. The induction of emotions requires a social or emotional interaction between them, for instance, when announcing news to someone or during a handshake. This type of induction may be difficult to achieve in an experimental setting, since it is difficult to obtain a natural social behavior after a briefing by the experimenter. This method is usually employed for inducing social stress [31]. Several studies have used this method to collect affective facial or gestural expressions [32].
- *Games.* A third approach to inducing affects is to use interaction applications such as games [33], [34]. Games motivate the users and lead them to forget about the experimental setting, while providing a controlled environment. Besides, this approach enables the induction of a variety of emotions (e.g., joy when winning, frustration when losing due to simulated lag). However, games have the disavantage that their running would depend on the action of the user. It is then important to ensure that the running would be comparable between different users.

2.3 Stress Measurement

Stress responses are not easy to measure, as the participants may not be fully aware of their own current affective state. To overcome this issue, both subjective and objective measurements have been proposed.

The Perceived Stress Scale proposed by [35] evaluates daily feelings of stress levels. Some other questionnaires focus on affective states related to stress as anxiety. This is the case of the State-Trait Anxiety Inventory [36]. This instrument differentiates state anxiety, which is anxiety about an event, from trait anxiety as a personal characteristic.

Stress can also be measured using more objective ways. [37] observed a tendency of electrodermal activity and heart rate to increase under stress. These responses can include several other physiological signals [38] (increased salivary cortisol levels, blood preasure and heart rate). Psychological studies have also demonstrated that spontaneous stress of people is closely linked to their approach and avoidance behaviors [39], [40].

Objectives of the current study. This summary of the state of the art has introduced the main methods for inducing spontaneous affective states to participants. These methods have been generally applied to investigate the facial and gestural expressions of emotions [32], [41]. Surprisingly, few studies have applied these methods to explore the haptic expression of spontaneous behavior. These studies investigate mainly the identification of physical features of spontaneous haptic expressions, but not the human capabilities to perceive these spontaneous states through collected haptic expressions.

The main objective of the current study is to investigate the haptic communication of a spontaneous stress state between two users using haptic devices. It focuses on both the characterization of the haptic expressions and the user's perception of this emotional state.

In the first step, we designed a task inducing stress and involving a haptic interaction. This task was used to collect and analyze haptic expressions of stress. The efficiency of the stress induction was analyzed using the validated subjective stress measurement methods. In the second step, we displayed the collected haptic expressions to users. The objective of this step was to investigate whether real users would be able to perceive the stress in the presented haptic expressions.

Therefore, we adopted a scenario based on an interactive game. Games have several advantages. They are familiar to people and able to motivate them. Moreover, they may effectively induce different emotions [34].

3 Experiment 1: Collection of a Corpus of Haptic Expressions of Stress

The study of the spontaneous haptic expressions of emotions is subject to several psychological and technological constraints. In a previous paper, we presented several methodological considerations concerning touch, emotions, and haptic technology [25]. The conclusions were that a task using a haptic interaction to collect expressions from spontaneous states should be easy to understand and motivate participants.

Our scenario is based on a racing arcade game displayed on a standard desktop computer with a 22 inch screen. The rule of the game is simple: a car is running on a three-lane road. On the road, several obstacles appear and must be avoided (see Fig. 1, first picture). These obstacles lead the participants to move the car, enabling us to analyze his or her movements.

In order to induce stress, the road visibility was then suddenly reduced by cutting the upper half of the screen without prior notice (Fig. 1, second picture). This reduces the ability of the participants to avoid the obstacles, leading to more potential collisions. This situation is suitable for stress induction as the users are expected to feel that they are not able to cope with the situation. Thus, the obstacles would appear at the last moment, making it more difficult to avoid them. The visibility was then restored (Fig. 1, third picture). The reduction of visibility did not change the task (i.e., driving and avoiding obstacles). Thus, the variations of the participants' behavior are expected to be directly linked to the stressful stimulus, which will be verified using tests.

3.1 Hypotheses

Our study investigates whether the reduction of the visibility does induce stress and influence the haptic behavior of the participants. The haptic features are split into two components: a kinematic component (movement's speed, fluidity, etc.) and a force component (exerted force on the haptic device).

To investigate the influence of a stress induced in the context of a video game, we analyzed three different phases of the task:

- P1 The phase preceding the stress induction (40 s).
- P2 The phase when the stressful stimulus is present (23 s).
- P3 The phase following stress induction (27 s).

The phase *P1* corresponds to our baseline. It represents the behavior of the participant during a normal state and lasts enough time for the participant to get used to the task. The phase *P2* differs from *P1* by the presence of a stressful stimulus. This phase enables determining the haptic behavior corresponding to a stressful state, in comparison with the baseline. The duration of this phase had to be at least 20 s as it represents a full cycle of obstacles. Finally, the phase *P3* follows the stress induction. It aims at determining whether the changes observed in the haptic behavior last in time, even after the end of the stressful stimulus. The time of this phase was set in order the whole experiment lasts 1'30 minutes.

We based our hypotheses on the success of the stress induction and the resulting haptic behaviors, based on [12], [42], [43] :

- H1 The reduction of visibility during the task (from *P1* to *P2*) induces stress. More precisely, participants report feeling stress during *P2*.
- H2 The haptic features (kinematic and force components) present differences between *P1* and *P2*. This hypothesis aims at pointing to a change in the haptic features during *P2*. More precisely:
  - H2-a Participants exert more force on the button during *P2* than *P1*.
  - H2-b Participants move faster during *P2* than *P1*.
  - H2-c Participants' motions are jerkier during *P2* than *P1*.
  - H2-d Participants use the first axis of movement more during *P2* than *P1*. The task requires only the use of the left–right axis. However, the participants controls the device in 3D space. This measure indicates how much the participant sticked to the main axis of movement.
  - H2-e Participants use the second axis of movement more during *P1* than *P2*. This corresponds to the degree of deviation from the main axis of the movement and is expected to be inversely proportional to the first axis of movement.
- H3 The haptic features (kinematic and force components) present differences between *P1* and *P3*. This hypothesis aims at pointing to a change in the haptic behavior remaining after the stressful event, when the task goes back to its normal state. More precisely:
  - H3-a Participants exert more force on the button during *P3* than *P1*.
  - H3-b Participants move faster during *P3* than *P1*.
  - H3-c Participants' motions are jerkier during *P3* than *P1*.
  - H3-d Participants use the first axis of movement more during *P3* than *P1*. This axis corresponds to the main axis of the movement, computed through principal component analysis ([44]). We investigate here the eigenvalue corresponding to this vector.
  - H3-e Participants use the second axis of movement more during *P3* than *P1*. This axis corresponds to the second main axis of the movement, computed through principal component analysis. We investigate here the eigenvalue corresponding to this vector.

H2 and *H3* verify respectively the changes in the haptic behavior (e.g., mean speed), during the stimulus and if it remains after removing the stimulus.

3.2 Experimental Setup

The experiment took place in an anechoic acoustic room to avoid any external visual or audio distraction. The participants were left alone in the room during the experiment.

The car driving game task was displayed on a 22 inch screen. The screen and a Geomagic Touch device were set on a desk (see Figure 2). To align the participant with the screen and the haptic arm, we used a special procedure. We asked them to put their two hands on two markers (hand shaped) positioned on the desk (See Figure 2).

The collected haptic features were computed only when the participants pressed the button. Making participants press the button ensured that they were driving the car. It also ensured that the participant exerted a pressure on this spot that we could measure. In order to measure the

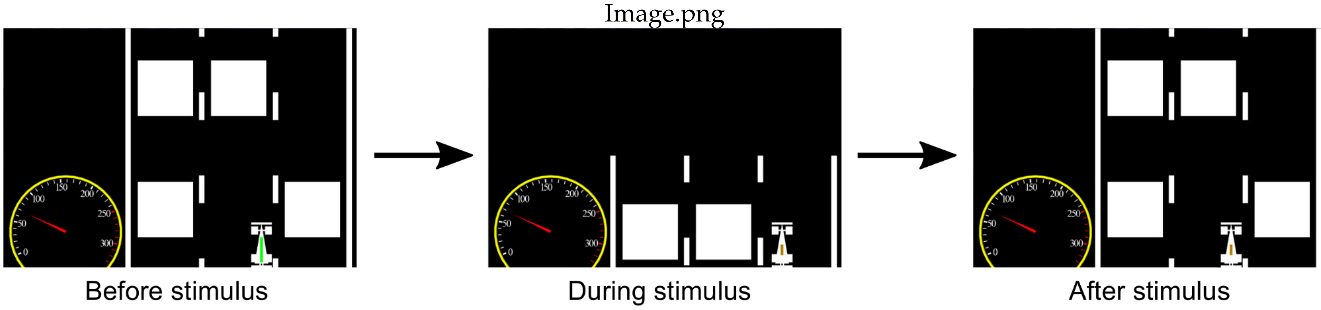


Fig. 1: The “car on a three-lane road” game task. Participants control the left–right position of the car with the haptic device. While the road scrolls, participants have to avoid obstacles (blank squares). At some point during the task, as a stressful stimulus the visibility is reduced.

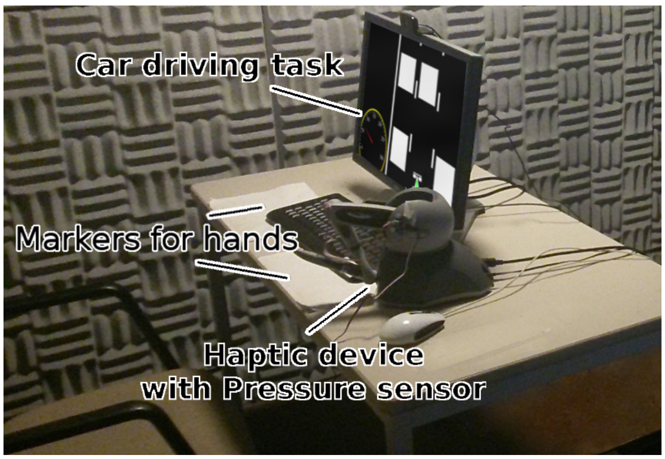
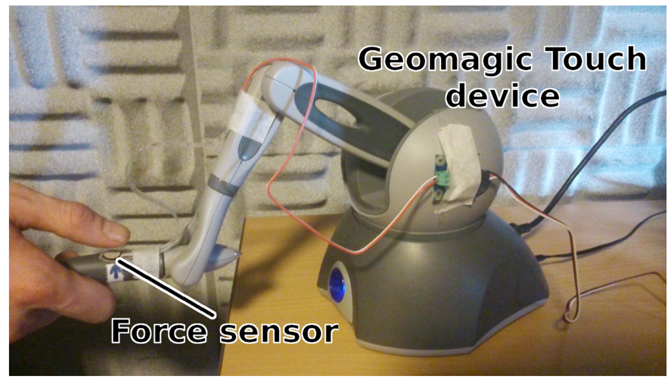
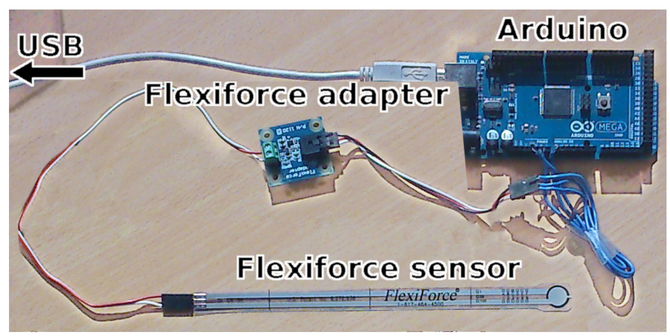


Fig. 2: Experimental setup to induce stress and collect the corresponding haptic expressions. The participants played the car driving game using the Geomagic Touch device. The computer recorded all the haptic behaviors of the participant.



(a) Geomagic Touch device augmented with a force sensor.



(b) Hardware design. A computer collects the data from the Flexiforce sensor via USB.

Fig. 3: Augmentation of a Geomagic Touch with a force sensor attached to its button.

force exerted by participants on the haptic device, a SEN-08713 FlexiForce force sensor[1] was attached to the button of the haptic device (see Figure 3a). Participants received precise instructions on the way to press the button. The pressure sensor was connected to an Arduino card to collect the corresponding data (see Figure 3b). A Flexiforce Adapter filtered the raw data.

3.3 Method

3.3.1 Participants

Sixteen right-handed males, average age 27 (SD = 3.6), ages 21–33, participated in this experiment. We chose only right-handed young males for this experiment in order to avoid the influence of differences in dominant hand, age, and gender on the results. It is well known that these parameters could influence the expression of emotions [45]. The objective of the experiment was hidden to the participants until the end of the experiment to collect behavior as natural as possible.

1. http://www.flexiforce.com/

3.3.2 Measures

3.3.2.1 Haptic expressions: We computed several force and kinematic measures inspired by previous studies and observed to be relevant for discriminating emotional haptic behavior [19], [46]. The force measure was computed from the force sensor data. The kinematic measures were computed from the sequence of 3D points $[(x,y,z)_1,(x,y,z)_2,...,(x,y,z)_n]$ corresponding to the recorded haptic expressions. The sampling rate was 1000 Hz. In the following, M_O stands for the objective measure, and M_S for the subjective measure.

- M_O1 Force intensity: Intensity of the force exerted on the device’s button (FlexiForce force sensor).
- M_O2 Mean Speed: Average speed of the end-effector.

- M_O3 Jerkiness: The degree of jerkiness of the expression. It was calculated using the equation $\sum_{t=0}^{n-1} \mid a(t+1) - a(t) \mid / n$, with $a(t)$ the acceleration at time t.
- M_O4 Weight of Major Axis: The prevalence of the major axis on the expression (computed with Singular Value Decomposition [47]).
- M_O5 Weight of Second Major Axis: The prevalence of the second major axis on the haptic expressions (computed with Singular Value Decomposition).

In order to provide the same level of difficulty and the same task features for all participants, a same sequence of twenty seconds, including 29 obstacles, was presented and looped during the game. This sequence was reset at the beginning of *P1*, *P2* and *P3* in order to enable the comparison of these three phases.

3.3.2.2 Stress induction: To investigate stress related feelings, we asked the participants several questions at the end of the experiment. The questionnaire was inspired by the Perceived Stress Scale [35]. The participants answered on a 5-point Likert scale (from 1 to 5):

- M_S1 "I understood the task." This allows verifying that the task was simple to understand. This is important since a misunderstanding of the task could introduce noise into the collected behavior ([25]).
- M_S2 "I thought I was controlling the situation (before this event)."
- M_S3 "I thought I was controlling the situation (after this event)."
- M_S4 I felt stress before the reduction of the visibility.
- M_S5 I felt stress during the reduction of the visibility.

Measures M_S2 and M_S2 enable to measure measure the evolution of the sensation of control during the task, according to the event. We also measured the level of stress, following a procedure similar to the Differential Emotional Scale [48] (M_S4 and M_S5). In order to hide the stress measurement from the participants, these two measure was blended with twelve other emotional states to evaluate. Indeed, participants reported a total of thirteen values corresponding each to an emotional state. Stress was one of presented items among others as joy or sadness.

3.3.3 *Experimental Procedure:*

The participants sat down in front of the computer screen (see Fig. 2). The experimenter presented the game to the participants (the rules, the interaction, obstacle management, etc.). The participants were told that the objective of the experiment was to evaluate the potential and contribution of a haptic feedback during a virtual task. The real objective of the experiment (studying haptic expressions of stress) was hidden from the participants.

The participants were then introduced to the haptic device. They received precise instructions on the way to hold it (as if they were grabbing a wrist: the thumb on the button of the device). They were asked to freely explore the accessible space. Then, the participants received some training for thirty seconds, during which the game task was explained.

During this task, participants had to continuously depress the button of the device to move the car. The first reason for this was to ensure that they were performing the task correctly. The second reason was to be able to measure the pressure they exerted on the device over the duration of the task. The speed the vertical speed of the car was fixed and constant during the whole experiment. No stressful stimulus was presented during the training. The experimenter asked them if they understood the task and if they had any questions. Before the experimenter left the room, he explained to the participants that the task would be the same as during the training, but with a duration of one and one-half minutes. Then, the experiment and the game began. At the 40th second, for 20 seconds thereafter, the upper half of the screen was masked (see Fig. 1). These durations were selected after preliminary tests.

At the end of the experiment, the experimenter returned to the room and asked each participant to complete the questionnaire presented above. Then, for ethical reasons, the experimenter explained to participants the real objective of the experiment (i.e., the study of the haptic expressions of stress).

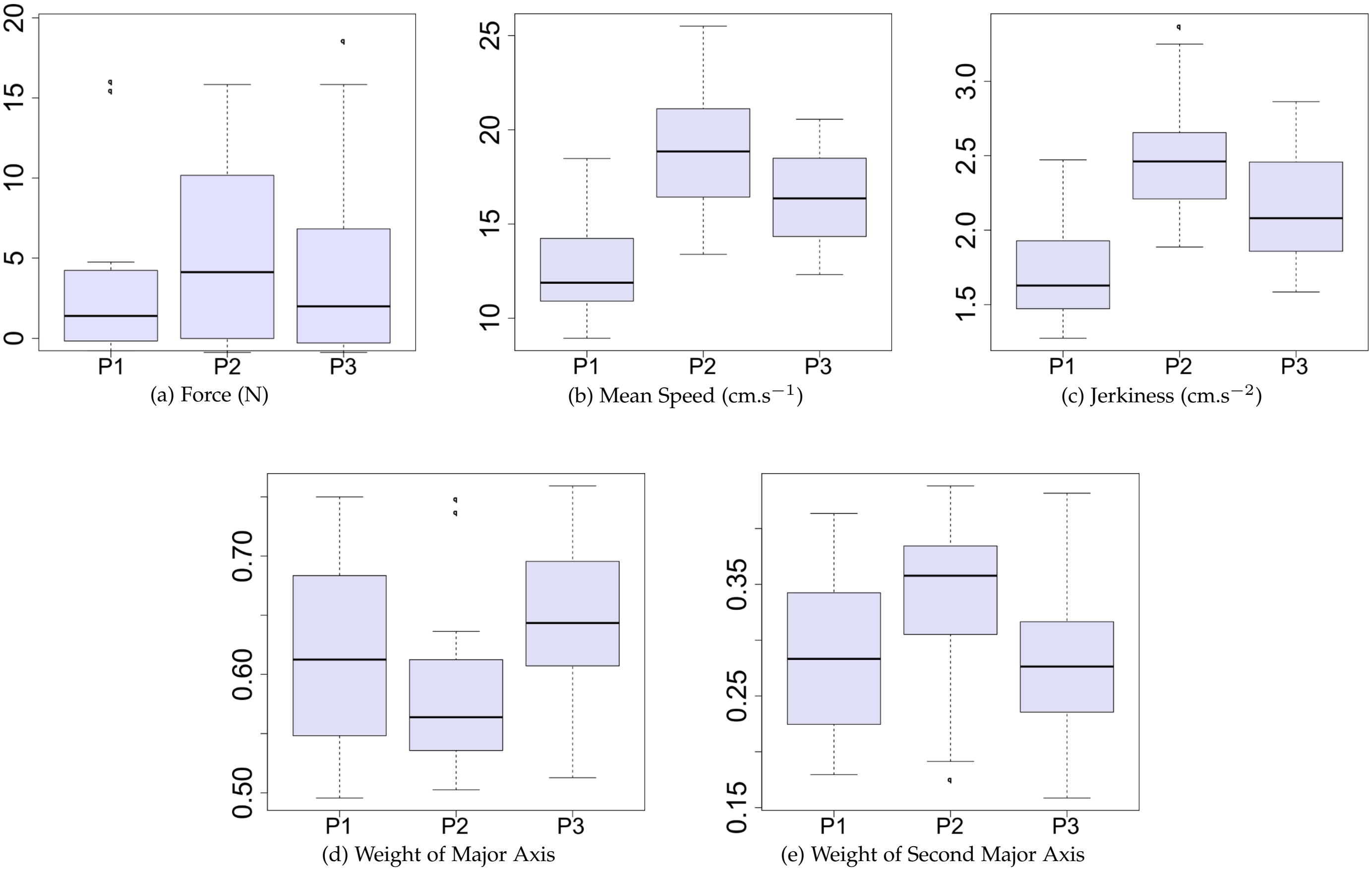
3.4 Results

Figure 4 presents the measures computed from the collected haptic expressions for the three phases *P1*, *P2* and *P3*. A Friedman test highlighted that the phase of the task had an influence on the collected measures. Table 1 presents the significant differences for these measures between the following pairs of phases: *P1* vs. *P2* and *P1* vs. *P3*. This analysis used a paired Wilcoxon signed-rank test as all participants completed all phases. Between *P1* and *P2*, the measures of the force (M_O1), the mean speed (M_O2), and the jerkiness (M_O3) present all significant differences (respectively, $p = .0319$, $p < .01$ and $p < .01$). This supports **H2** for these measures. The test did not highlight a significant difference between *P1* and *P2* for the weight of the second major axis (M_O5, $p > .05$). Between *P1* and *P3*, the measures of the mean speed (M_O2), and the jerkiness (M_O3) present significant differences ($p < .05$). This supports **H3** for these measures. The test did not highlight a significant difference between *P1* and *P3* (M_O4, $p > .06$). It is interesting to note that some p-values are close to the significance threshold. Then, it might worth investigating the corresponding measure further.

Concerning the subjective results, the participants understood the task ($M_S1 = 5.00$, SD $= 0.00$). They also reported that they felt less in control of the task in *P3* compared to *P1* ($M_S2 = 4.50$ vs. $M_S3 = 3.75$, p-value $= .0213$, $W = 78$). For M_S4 and M_S5, participants reported feeling surprised at the very beginning of the stimulus, and alerted during the whole stimulus. Concerning stress, participants reported feeling less stress in *P1* compared to *P2* (1.63 vs. 3.12). No differences were observed for other emotions. These results support **H1** as the decrease of feeling of control is a sign of stress [11].

4 Experiment 2: Perception of the Kinematic Component of the Spontaneous Expressions

The previous experiment highlighted statistical differences in the haptic behavior of participants in *P1*, *P2* and *P3*.



(a) Force (N)
(b) Mean Speed (cm.s^{-1})
(c) Jerkiness (cm.s^{-2})
(d) Weight of Major Axis
(e) Weight of Second Major Axis

Fig. 4: Computed measures for the phases *P1*, *P2*, and *P3*.

TABLE 1: Mean values and standard deviations for each measure for *P1*/*P2*/*P3*. The two last columns compare the results: *P1* vs. *P2* and *P1* vs. *P3*. Bold values are significant values (i.e., $p < .05$). Numbers in italic are tendency values (i.e., $p < .1$).

Measure - Result	Phase during task: P1	P2	P3
M1 Force N (SD)	4.13 (5.2)	6.35 (6.21)	5.04 (6.03)
M2 Mean Speed cm.s^{-1} (SD)	12.7 (2.59)	19.0 (3.17)	16.3 (2.46)
M3 Jerkiness cm.s^{-2} (SD)	1.17 (0.367)	2.50 (0.426)	2.16 (0.376)
M4 Weight of Major Axis	0.613 (0.0785)	0.586 (0.0715)	0.647 (0.0730)
M5 Weight of 2nd Major Axis	0.284 (0.0737)	0.340 (0.0768)	0.283 (0.0757)

Measure - Analysis	Friedman (X^2)	Comparison: p-value (V) P1 vs. P2	P1 vs. P3
M1 Force	**.00901 (9.42)**	**.0319 (26)**	.979 (69)
M2 Mean Speed	**1.29e-6 (27.1)**	**.000482 (0)**	**.000482 (0)**
M3 Jerkiness	**1.22e-05 (22.6)**	**.000584 (1)**	**.000482 (0)**
M4 Weight of Major Axis	**.0339 (11.4)**	.518 (0.0715)	*.0664 (32)*
M5 Weight of 2nd Major Axis	**.0152 (8.38)**	*.0525 (30)*	.856 (72)

These results revealed specific haptic features, for both the kinematic and force components, for this emotional state. The subsequent experimental study aimed to investigate whether these differences are haptically perceptible using a subjective assessment. In a first time, we investigated the perception of the kinematic component of haptic expressions with a kinesthetic feedback. The perception of the force component was investigated separately in the next section of the paper as there is no device currently available able to display simultaneously exerted force and kinematic expressions.

4.1 Objectives and Hypotheses

This experiment aimed to investigate whether new participants perceive changes in the kinematic features of the collected haptic expressions as well as a stress between the different phases of a session (*P1*, *P2* and *P3*). The different hypotheses were formulated according to the statistical differences previously observed.

H4 Participants perceive differences in the kinematic component between *P1* and *P3*. This hypothesis aims to verify that the statistical differences described in the previous section are perceptible by new participants, while the task was exactly performed in the same conditions. We expect results in accordance with these statistical differences:

H4-a Participants perceive a higher speed in the expression in *P3* compared to *P1*.

H4-b Participants perceive a jerkier expression in *P3* compared to *P1*.

H5 Participants perceive more stress in the kinematic component in *P3* compared to *P1*. This last hypothesis attempts to verify that participants succeed in discriminating a stressful state from a normal state.

4.2 Experimental Setup

The experiment took place in the same anechoic acoustic room as the previous experiment, to avoid any external visual or audio distraction. The experimental platform was also similar (See Figure 2). Indeed, the experiment aimed to provide the same context as the previous experiment. The participants sat down in front of a 22 inch computer screen. The screen displayed the forms to be completed by the participants. The participants interacted with the graphic user interface using a keyboard. The same haptic device as in the previous experiment was used to render the recorded haptic expressions. The device rendered the expressions by following the succession of 3D points in space recorded during the car driving task.

4.3 Method

4.3.1 Participants

Fifteen right-handed males, average age 25 (SD = 4.6), ages 19–37, participated in this experiment. We chose only right-handed young males for this experiment in order to avoid the influence of differences in dominant hand, age, and gender on the results [45]. The participants were different from those of the previous experiment.

4.3.2 Conditions

In this experiment we displayed several pairs of kinematic expressions to participants. Each pair of expressions was presented according to two conditions as follows:

C1 The first presented expression was randomly selected from the set of expressions obtained in *P1*. The second expression corresponded to the expression collected in *P3* and made by the same participant.

C2 The first presented expression was randomly selected from the set of expressions obtained in *P3*. The second expression corresponded to the expression collected in *P1* made by the same participant.

To avoid learning from previous presented pairs of expressions, the condition (*C1* or *C2*) was randomly selected for each presented pair of expressions.

4.3.3 Measures

We collected the following subjective measures from the participants during the experiment. The participants evaluated this set of measures after each pair of presented intensities of kinematics:

M_S1 Mean speed. This measures the perception of mean speed (*H4-a*).

M_S2 Jerkiness. This measures concerns the perception of jerkiness (*H4-b*).

M_S3 Presence of stress. This measures the subjective perception of stress in the stimuli (*H5*).

Each measure was evaluated by participants using a 5-item Likert scale from 1 to 5. Participants assigned a rank of 3 if they perceived no difference between the two stimuli for a measure. 1 means the participant perceived the first presented expression as having the higher value for the evaluated measure. 5 means the participant perceived the second presented expression as having the higher value for the evaluated measure.

4.3.4 Experimental Procedure

The participants started the experiment by completing a form asking for their age, gender, and dominant hand. The experimenter explained to them that they would haptically perceive pairs of expressions using a haptic device (see Figure 6a). They were informed that all presented expressions were issued from a previous study. The participants were asked to play the car game (see experiment 1) for thirty seconds. This aimed at helping them understanding the context and the origin of the expressions. The participants were also informed that for each presented pair of expressions, one of them had been recorded after the induction of a stress. However, there was no mention of the specific stimulus used to induce the stress to avoid any biais.

Finally, the experimenter explained to the participants how to report their evaluation of each pair of expressions using the keyboard and the GUI (see Figure 6b). The participants evaluated a training pair, and asked for questions. Then, the experimenter left the room and the experiment began. The experiment ended when the sixteen pairs of expressions had been evaluated. Each pair corresponded to one participant of the previous experiment.

4.4 Results

We compared the answers of the participants for the subjective assessment of the pairs of expressions from *P1* and *P3* using an independant Wilcoxon signed rank test. The results showed similar perception for the mean speed (M_S1), the jerkiness (M_S2) and stress (M_S3) between the two conditions. These results mean there is no significant difference for the whole set of collected haptic expressions. Nevertheless, it is possible that there are some couples of collected expressions where there are perceptible differences for the mean speed, the jerkiness during stress induction.

We conducted a Spearman's correlation test to verify the existence of such links between haptic features and stress. This test revealed a correlation between the objective difference between *P1* and *P3* for the mean speed and the subjective assessment of the differences of the mean speed ($M_S1, p < .01, S = 213, \rho = 0.686$). The higher the objective difference for the mean speed between *P1* and *P3*, the more it was perceived by participants. No correlation was found for the jerkiness (M_S2).

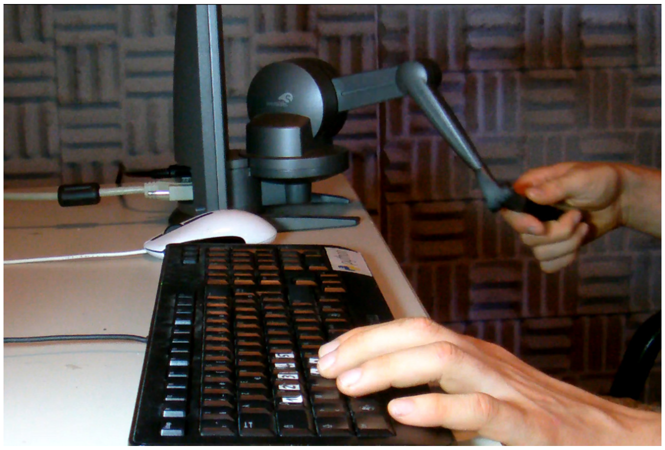


Fig. 5: Participant using the Geomagic Touch X to render the haptic expressions. He reports his evaluation using the keyboard after a couple of haptic expressions were rendered on the Geomagic Touch X device.

Fig. 6: Participant interacting with the experimental platform.

Concerning stress perception, the Spearman's correlation test revealed a high correlation between the subjective assessment of the difference of the mean speed and the perceived stress ($p < .01, S = 190, \rho = 0.825$). The more important the perceived difference of the mean speed between *P1* and *P3*, the more the participants perceived stress. Considering these results, we carried out a correlation test between the objective difference of mean speed and the subjective assessment of the stress, highlighting a slight correlation between them ($p = .0365, S = 322, \rho = 0.526$).

As highlighted by the correlation tests between the objective and subjective measures, the participants perceived more difference in the mean speed between the pairs of expressions when the objective difference was substantial.

Considering these results, we filtered the haptic corpus in order to keep only the pairs of haptic expressions presenting the highest differences for the mean speed (see Table 2). We kept half of the pairs of haptic expressions (eight pairs) displaying the highest objective differences for the mean speed (M_S1) between *P1* and *P3*.

For the eight filtered pairs of expressions, there was no statistical differences for the assessment of the jerkiness (M_S2). Concerning the mean speed, under *C1*, the participants perceived a higher mean speed in the second presented expression ($M = 3.34, SD = 1.40$) (see Table 2) than in the first presented expression. In contrast, under *C2*, the participants perceived a higher mean speed in the first presented expression ($M = 2.75, SD = 1.40$) than in the second expression. A Wilcoxon signed-rank test found a difference between the two conditions ($p = .0211, W = 2230.5$). These different results support *H4-a*, but not *H4-b*.

Concerning stress perception, under *C1*, the participants perceived a higher stress in the second presented expression ($M = 3.492, SD = 1.49$) than in the first presented expression. In contrast, under *C2*, the participants perceived a higher stress in the first presented expression ($M = 2.97, SD = 1.44$)) than in the second presented

TABLE 2: Differences in mean speed and stress perception according to the conditions. For both measures, participants perceived the second presented stimulus to be higher in *C1* and lower in *C2*.

Mean speed evaluation	C1	C2
5	26 %	19 %
4	17 %	22 %
3	20 %	18 %
2	18 %	16 %
1	17 %	23 %

Stress evaluation	C1	C2
5	31 %	19 %
4	17 %	22 %
3	20 %	20 %
2	10 %	17 %
1	20 %	19 %

expression. A Wilcoxon signed-rank test found a difference between the two conditions ($p = .0432, W = 2175$). This result supports *H5*.

5 Experiment 3: Perception of the Force Component of the Spontaneous Expressions

In this study, we investigated whether the participants perceived a change in the force component of the haptic expressions and if they associated the change with stress. As explained before, due to technical constraints, the kinematic and intensity of the force component were investigated separately.

This intensity of force exerted had been recorded with a force sensor in the first experiment. In the experiment being presented now, the intensity of the force was applied to the participant's finger with a special haptic device that we built especially for this experiment. The haptic device rendered the mean intensity of the force component and not the dynamic expression. The system was not reactive enough to ensure a satisfying haptic rendering of a dynamic expression.

5.1 Hypotheses

The statistical analysis of the movements of the participants in the first experiment has shown that there was a difference in the exerted force between *P1* and *P2* (see the results of the first experiment), but no difference was observed between *P1* and *P3*. Then, comparing *P1* and *P3* in terms of perceptive evaluation might not provide results. The exerted force had no influence on the task. Thus, the increase in this measure corresponds to a change in the participants' behavior. For this reason, we proposed to focus on the phases *P1* and *P2*.

To study how the increase in the exerted force is perceived by participants, we made the following hypotheses:

- H6 Participants perceive a higher intensity of force for haptic expressions obtained during *P2* than *P1*. This hypothesis aims at verifying that the statistical differences that we observed are perceptible by the participants.
- H7 Participants perceive stress in expressions presenting a higher intensity of force. This hypothesis aims at checking whether participants associate the exerted force with the stressful stimulus.

5.2 Experimental Setup

The experiment took place in the same anechoic acoustic room as the previous experiments. The experimental platform was similar to the one used in the previous studies (See Figure 8) and the participants were installed in the same way (sitting in front of a computer). However, a special haptic device (ANGEL device) was designed and developed to apply the force to the participant's finger (see Fig. 7a).

The participant put his finger (thumb) inside a clamping mechanism (see Fig. 7a). The mechanism was composed of a fixed part (gray structure) and a mobile part (blue structure). The mobile part could move along a rack and was actuated with a motorized pulley. The actuator was a Dynamixel AX-12A (see Fig. 7b). A Robotis CM-510 controller connected the actuator to the PC through a USB2Dynamixel component. A force sensor was used to control the intensity of the force exerted on the finger (the same sensor as in experiment 1). The intensity of the force presented corresponded to the intensity measured with the force sensor in the first experiment. A red button on the keyboard provided for the immediate stopping of the haptic device to release the finger, in case of problems. The different components used to design the haptic device came from the Bioloid Kit[2]. Pretests were conducted to ensure that the applied force did not discommode the participants.

5.3 Method

5.3.1 *Participants*

Ten right-handed males, average age 27 (SD = 3.1), ages 22–32, participated in this experiment. We selected right-handed young males for this experiment in order to avoid the influence of differences in dominant hand, age and gender on the results.

5.3.2 *Conditions*

In this experiment we displayed several pairs of forces to participants. Each pair was presented according to two conditions as follows:

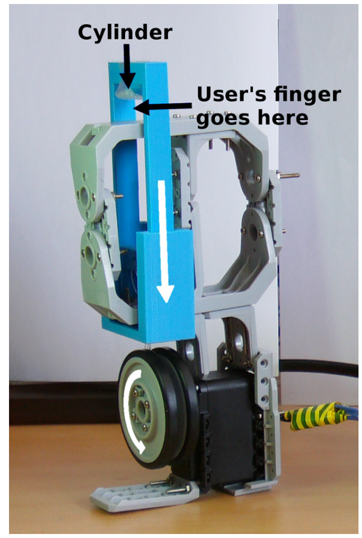
- C1 The first presented force was randomly selected from the set of expressions obtained in *P1*. The second expression corresponded to the expression collected in *P2* and made by the same participant.
- C2 The first presented force was randomly selected from the set of expressions obtained in *P2*. The second expression corresponded to the expression collected in *P1* and made by the same participant.

To avoid learning from previous presented pairs of expressions, the condition (*C1* or *C2*) was randomly selected for each presented pair of expressions.

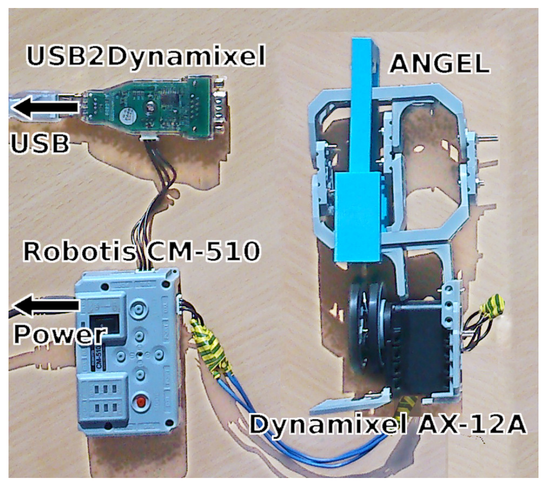
5.3.3 *Measures*

We collected the following subjective measures. The participants evaluated this set of measures after each pair of forces:

2. http://www.robotis.fr/bioloid/32-kit-bioloid-premium.html



(a) The ANGEL device. The participant places his thumb inside a clamping mechanism. The mobile part (blue part) moves vertically along a rack and is actuated with a motorized pulley.



(b) Hardware control of the ANGEL device. A Robotis CM-510 controller connects the actuator to the PC through the USB2Dynamixel.

Fig. 7: ANGEL: A haptic device designed to apply a slight force to the finger.

- M_S1 Force intensity. This measures the perception of the force exerted on the thumb. This measure evaluates *H6*.
- M_S2 Presence of stress. This measures the subjective perception of stress in the stimulus. This measure evaluates *H7*.

Each of these criteria were evaluated by the participants using a 5-item Likert scale from 1 to 5. 1 means the participant perceived the first force (C1) as having the higher value for the evaluated measure. 5 means the participant perceived the second force (C2) as having the higher value for the evaluated measure. Participants assigned a ranking of 3 if they perceived no difference between the two stimuli.

5.3.4 Experimental Procedure

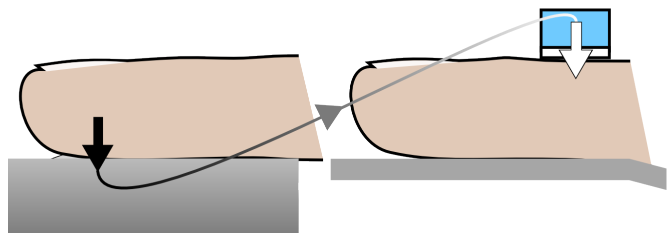
Participants started the experiment by completing a form asking for their age, gender, and dominant hand. The experimenter explained to the participants that they would perceive pairs of forces on their thumb. They were informed that all these forces had resulted from a previous experiment. The experimenter presented a video introducing the car game (see experiment 1). The participants were also informed that for each pair of forces, one of the two had been recorded after a stress induction. However, there was no mention of the stimulus used to induce the stress.

The ANGEL devices were then presented to the participants. One was fixed on the desk in front of the right hand of each participant. The working of the device was explained to the participants, in particular, how to hold the device (see Figure 8a). Then, some sample forces were applied to each participant's thumb (see Figure 8b). The applied force was presented as the force applied by the finger belonging to somebody else.

Finally, the experimenter explained to the participants that for each pair of forces, they had to complete an evaluation form. They had to report which of the two stimuli had the highest force intensity, and which one they thought had been recorded after the inducement of a stress. The participants evaluated the training pairs and asked questions, if any.

At the end of the training session, the participants were left alone in the room. The experiment ended when they evaluated the sixteen pairs of force.

(a) Experimental protocol including the ANGEL device. The user places his thumb in the device and perceives a pressure on it. He wears hearing protection to avoid hearing the actuator of the device.



(b) The pressures recorded on the button of the device in experiment 1 (black arrow) are applied to the thumb of somebody else (white arrow).

Fig. 8: Experimental protocol and pressure rendering.

5.4 Results

We compared the answers of the participants for the subjective assessment of the pairs of forces from *P1* and *P2* (see Table 3) using an independant Wilcoxon signed rank test. For the exerted force (M_S1), under *C1*, the participants perceived a higher intensity in the second expression ($M = 3.62, SD = 0.95$). In contrast, under *C2*, the participants perceived a higher intensity in the first expression (2.29, SD = 0.84). A Wilcoxon signed-rank test showed that this difference is highly significant ($p < .01, W = 5133$). This result supports *H6*.

For M_S2, under *C1*, participants were not able to perceive a difference in the stresses of the two expressions ($M = 3, SD = 1.07$). However, under *C2*, participants perceived a higher stress in the first expression ($M = 2.66, SD = 1.05$). A Wilcoxon signed-rank test showed that this difference is significant ($p = .0296, W = 3628$). This result supports *H7*.

We also investigated the link between the intensity of the force and perception of the stress. Spearman's correlation test found a high correlation between the objective and subjective assessments of the difference between the intensities of the forces ($p < .01, S = 69.1, \rho = 0.898$). Spearman's correlation test found a correlation between the stress perception difference and the subjective assessment of the difference of the force intensity ($p < .01, S = 201, \rho = 0.704$). Further, Spearman's correlation test found a correlation between the objective assessment of the difference of the force intensities and the difference in the perceptions of the stresses ($p < .01, S = 244, \rho = 0.640$). These results show that the more the participants perceived a difference in force intensity, the more the expression presenting the highest intensity was associated with the stressful stimulus.

TABLE 3: Differences in pressure and stress perception according to the conditions. For both measures, participants perceived the second presented stimulus to be higher in *C1* and the first stimulus to be higher in *C2*.

Pressure evaluation	C1	C2
5	21 %	1 %
4	22 %	3 %
3	54 %	44 %
2	2 %	24 %
1	0 %	26 %

Stress evaluation	C1	C2
5	8 %	6 %
4	17 %	6 %
3	50 %	53 %
2	9 %	15 %
1	12 %	18 %

6 Discussion

This section discusses the results of the three experiments described in the previous sections.

6.1 Considerations on the stress induction

It is important to ensure that the proposed experimental protocol (car game) correctly induced stress in the participants. As all participants reported they fully understood the task, it is unlikely that a change of behavior resulted from a misunderstanding of the task. The task was also simple, and required continual interaction, designed to maintain the participant's attention.

In the subjective feedback, the participants reported they thought they were losing control of the situation during *P2*, compared to the beginning of the experiment (*P1*). This is an indicator of stress [10], [35], supporting **H1**.

6.2 Haptic expression of stress

The first experiment highlighted the objective differences in both the kinematic and force components in *P3*. While **H2** is supported, in this paper did not consider the changes in the kinematic component of the haptic expressions occurring during *P2*. In fact, these changes are linked to the task's features: the obstacles appeared at the last moment, forcing the participants to react quicker. Thus, the changes might be explained not by the presence of the stress, but by the reduction of the visual display. A comparison of the kinematic features between *P1* and *P3* showed an increase in the mean speed and jerkiness of the haptic expressions from *P1* to *P3*, supporting **H3**.

This is in line with the work of Yamauchi [43], who considered the same issue in the context of interaction with a mouse. He observed irregular gestures of the mouse during anxiety. As reported by some participants in our study, they remained stressed in *P3*, as they thought that something else might happen again. The weight of the major axis was significantly lower during *P2*. This means that the participants moved more along the other axes during the stimulus. This is due to the presence of the stimulus (not the stress), which led to a loss of control of the situation.

Concerning the exerted force, we observed an increase during *P2*. The exerted force had no influence on the task. Thus, the increase of this measure corresponds to a change in the participants' behavior due to stress. This result is supported by other studies, which have observed an increase in the applied force in case of stress [12], [42].

Under stress, the participants were faster and jerkier, and they applied a greater force on the device.

6.3 Haptic perception of stress

In experiment 2 we did not find any difference in the perception of the jerkiness, or second axis of haptic expressions. However, there was a difference for mean speed, partially supporting **H4**. This is surprising, as experiment 1 highlighted objective differences (statistically assessed) for these measures. This means that these objective differences were not big enough to be perceived by participants. In fact, we found a correlation between the objective differences of mean speed and the perceived differences of mean speed. The more important the objective difference in the mean speeds, the more the participants perceived the difference. To verify this idea, we filtered the corpus to keep the pairs of expressions presenting the highest differences in mean speed (objectively measured). This new analysis showed a significant difference for the perceived mean speed. We also observed in this case differences in stress perception, and in general a correlation between mean speed perception and stress perception. This suggests that the participants assimilated the highest mean speed with the presence of stress, supporting **H5**. This was observed in experiment 1 with the objective measures.

The results from experiment 3 highlighted differences in the perceived exerted force between *P1* and *P2*. They reported differences in stress perception for these phases, supporting **H6** and **H7**. We also observed a correlation between both measures. This suggests that the participants assimilated the most important intensity of force to the presence of stress. This was also observed in experiment 1 with the objective measures.

6.4 Limitations

Our study displays four main limitations. irst, our population of participants was restricted to young, right-handed men to avoid the impact of differences in dominant hand, age, and gender on the results. This limits our results to this population. Future research should investigate whether the haptic behaviors observed could be generalized to other populations.

Second, we measured the stress responses of participants using only subjective measures. More objective stress measurements as postural reactions should be considered [49].

Third, in experiments 2 and 3, the couple of haptic expressions were presented only once to participants. For each couple of presented haptic expressions, participants perceived either firstly the expression recorded before stress, and then the one recorded after/during stress (or the other way round). Not using repeated trial weaken the results. However, this also reduces the duration of the experiments, which were focused on spontaneous expressions and evaluations. Then, it was crucial to avoid haptic fatigue and boredom for participants.

Finally, the perception of stress is evaluated after the perception of the features of the haptic expressions. This might imply that the perception of the stress was influenced by the evaluated features. Although participants might have evaluated the presence of stress based on the features they previously reported, they still correctly associated the values of the features with the presence (or absence) of stress.

7 CONCLUSION

Existing protocols to collect and render affective haptic expressions use acted expressions of emotions. However, it is well known that there are differences between acted and spontaneous expressions of emotions. While the spontaneous expressions of emotions have been well studied for facial and gestural modalities, they have been little investigated for the haptic modality.

In this paper, we firstly reported some methodological considerations for collecting spontaneous haptic expressions of emotions. Then, we proposed a relevant scenario based on an interactive game to collect haptic expressions of emotions. A statistical analysis showed that after inducing stress, haptic expressions presented a higher mean speed and jerkier movements. Furthermore, an increase of the intensity of the force exerted on the haptic device was observed during the stressful stimulus. Then, these measures could be used to determine stress level during this type of game play. We also studied the perception of the collected spontaneous haptic expressions of stress. The results showed that users were able to perceive the differences of mean speed and force intensity. Based on these differences, they succeeded in identifying the haptic expressions conveying a spontaneous stress. This means that it would be possible to convey a spontaneous stress through the haptic modality during of a remote interaction with a standard haptic device.

The current studies were preliminary studies on the possibility to convey spontaneous affective states through mediated haptics. Future researches will investigate the haptic expression of different kind of stress, as social stress. They will also investigate the haptic expressions and perception of other emotions, such as joy or anger, usually found in natural human–human communication. In particular, it could be interesting to investigate the emotional properties on the haptic corpus to induce stress. In a more long-term perspective, it could be interesting to determine if users could perceive affective states without telling them the states that are conveyed in the haptic expressions. We will also consider the integration of the haptic expressions with other modalities. A possible future application of these results could be the automatic recognition of affective states with the haptic modality.

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