Haptic Human-Robot Affective Interaction in a Handshaking Social Protocol

ABSTRACT

This paper deals with the haptic affective social interaction during a greeting handshaking between a human and a humanoid robot. The goal of this work is to study how the haptic interaction conveys emotions, and more precisely, how it influences the perception of the dimensions of emotions expressed through the facial expressions of the robot. Moreover, we examine the benefits of the multimodality (i.e., visuo-haptic) over the monomodality (i.e., visual-only and haptic-only). The experimental results with Meka robot show that the multimodal condition presenting high values for grasping force and joint stiffness are evaluated with higher values for the arousal and dominance dimensions than during the visual condition. Furthermore, the results corresponding to the monomodal haptic condition showed that participants discriminate well the dominance and the arousal dimensions of the haptic behaviours presenting low and high values for grasping force and joint stiffness.

1. INTRODUCTION

Nonverbal expressions are often used to communicate emotions between people (including prosody, facial expressions, body movements and hand gestures). Unfortunately, research in embodied communication and human-robot interaction are not yet able to reproduce the full potential of human-human affective communication.

The use of the haptic modality in human-computer interaction opens up new prospects. Interpersonal haptic interaction gives access to various pieces of information through complementary perception mechanisms such as tactile and kinesthetic channels. Psychological studies suggest that the haptic channel plays a very important role in social interactions [1, 2]. It can communicate positive/negative emotions and enhance the meaning of other verbal and nonverbal communication. In the field of physiology of tactile receptors, recent studies highlighted specific biological systems and perception mechanisms that are dedicated to the expression and perception of emotions through these haptic channels [3].

Different researches in psychological theories of emotions suggest a strong link between emotions and the body. For example, the Component Process Model [4] considers the following components of emotions: a neurophysiological component (bodily symptoms), a motor expression component, a motivational component (action tendencies), a cognitive component (appraisal), and a subjective feeling component (emotional experience). Haptics is therefore a relevant channel to investigate embodied cognition during human-robot affective interaction since it involves a physical contact and interaction between the user's body and the robot [5].

In order to improve the emotional expressiveness of robots, we proposed in this paper to combine their facial expressions with a haptic component through a handshake. This multimodal stimulation aims at improving the perception and discrimination of emotions during social interactions. The robot used its arm to shake the human hand with several haptic parameters such as the grasping force and the stiffness of movement of the robot arm. To provide relevant and efficient haptic expressions during social human-robot interaction, this research investigated how these haptic parameters influenced the perception of emotions expressed with the facial expression of the robot. More precisely, we studied the influence of the haptic parameters on the perception of the dimensions of emotions. This study used the PAD dimensional space to assess the elicited emotions [6]. This space describes the emotions using three uncorrelated and continuous dimensions: 1) Pleasure (P): degree of well-being (also called Valence) ; 2) Arousal (A): degree of mental or physical activity ; and 3) Dominance (D): degree of control of a situation.

The rest of the paper is structured as follows: Section 2 presents a state of the art that deal with Human-Robot interaction and affective haptics. Section 3 presents our approach and the working hypotheses. Section 4 details the experimental design and the robotic platform used for this experiment. Sections 5 and 6 present and discuss the experimental results. Finally, Section 7 concludes our paper.

2. STATE OF THE ART

In the field of mediated communication and Human-Computer Interaction, several works studied the potential of the haptic channels to support affective communication [2, 7]. They investigated different stimulation strategies (pneumatic, thermal, kinesthetic, etc.) according to different interaction configurations (e.g., handshaking, smartphone, etc.). They observed that haptics might correctly convey some dimensions of emotions, such as arousal [8] and valence [9], while providing a better social presence of the remote partner or of an autonomous virtual agent.

The use of haptic channel for human-robot affective and social in-

teraction represents a new challenge. In fact, even if researches in robotics that address facial, gestural, and postural expressions of robots are beginning to show relevant and reliable results [10, 11], the haptic human-robot interaction presents basic issues both from a psychological and technological perspective. The haptic creature, designed by Yohann and McLean [12], was one of the first projects that deal with affective haptics for social interaction with animal-like robots. The combination of different tactile stimulation techniques allows the perception of some categories of positive emotions [13]. In the context of human-robot collaboration, Groten [14] investigated how haptic feedback affects the perception of dominance. The objective of this work was to design a control strategy that allow a fast decision making for the human user during the collaborative manipulation of shared objects with a robot. The affective handshake with humanoid robots is a specific issue since it requires a direct contact with the robot during the interaction. Several researches investigate motion models that provide acceptable human-robot handshake interaction [15, 16]. Wang et al. [17] developed an advanced controller that interactively respond to the user behavior during the handshake. The controller is based on the hidden-Markov-model approach to estimate the human interaction strategy. The evaluation of the controller showed a physical behavior close to human-human handshake.

3. OBJECTIVE AND HYPOTHESIS

3.1 Objective of the study

Even if the realism of human-robot handshake has been considered in several works, its role to convey social and affective messages remains to be addressed. In fact, the handshake plays a key role in the interpersonal communication in everyday life. It can effectively support affective messages through haptic channel without requiring other feedbacks [1]. The main objective of this work is to investigate how the haptic feedback involved during the human-robot handshake can convey emotions, and more precisely, how it influences the perception of emotions expressed with facial expressions of the robot. The study focused on the influence of the haptic feedback on the perception of the dimensions of emotions in a subspace of the PAD space [6], namely: arousal and dominance. These two dimensions are generally not well supported by facial cues. The study was carried out with a humanoid robot that can express various emotions with facial expressions by controlling lips display, eye orientations, and eyelid opening. The humanoid robot is equipped with an anthropomorphic arm that can be used for a handshake with a human user. The arm can be controlled with various parameters and can provide different haptic behaviors during the human-robot physical interaction.

The work of Hertenstein and Keltner [1] highlighted eight main physical behaviors during human-human haptic interaction: hitting, grasping, trembling, shaking, swinging, lifting, stroking and pushing. For instance, subjects used the squeezing to communicate Anger and the stroking to communicate Sadness. Moreover, Hertenstein and Keltner [1] observed that the haptic intensity played an important role in the recognition of some emotions. In parallel with that work, Groten [14] showed that, during human-robot collaboration, the joints' stiffness of the robot arm influence the perception of dominance. Based on these different results and according to the haptic capacities of the robot's arm, we focused in this study on two haptic parameters of the handshake: (1) the grasping force of the robot's hand ; and (2) the stiffness of the movement of the robot's arm. For each parameter, we investigated two intensities: weak and strong. The haptic parameters were combined to provide four haptic behaviours for the robot's arm during the handshake. Based on the facial expressions of the robot and the haptic behaviours of its arm, a multimodal emotional interaction is provided to users during the handshake. The experimental study presented here proposes to investigate the influence of the haptic parameters on the perception of the arousal and the dominance dimensions of the emotions expressed with the facial expressions of the robot. In this study, we were interested in three basic emotions presenting different valence values: i) Sadness (negative valence); ii) Joy (positive valence) ; and iii) Neutral (neutral valence).

3.2 Hypothesis

The experiment tried to address tree main issues. First, we investigated if the studied facial expressions lead to a good estimation of their arousal and dominance. Second, we study how users evaluate the dimensions of the values of the two haptic parameters. We focus in this study on the haptic behaviours of the handshake that provide either high or low values for the two haptic parameters. Finally, we propose to compare the multimodal emotional interaction with the visual only (i.e., facial expression) and haptic only (i.e., handshake) interaction. The objective of this comparison is to highlight the effect of each modality on the perception of the two emotional dimensions in the multimodal configuration.

The following hypotheses were considered:

H1: The dimensions of the facial expressions are well discriminated.

Investigated dimensions: valence, arousal and dominance.

H2: The dimensions of the haptic expressions are well discriminated.

Investigated dimensions: valence, arousal and dominance.

H3.a: The multimodal (i.e., visuo-haptic) condition presenting high values for grasping force and stiffness of movement are evaluated with higher values for the dimensions than the visual condition.

Investigated dimensions: arousal and dominance.

H3.b: The multimodal (i.e., visuo-haptic) condition presenting high values for grasping force and stiffness of movement are evaluated with higher values for the dimensions than the haptic condition.

Investigated dimensions: arousal and dominance.

4. EXPERIMENTAL DESIGN

4.1 Robotic platform

The experiments presented in this work have been conducted with the Meka robot (see Figure 1). The Meka robot has been designed to work in human-centered environments. The robot features compliant force control throughout its body, a sensor head, durable and strong hands, and an omnidirectional base with Prismatic Lift. Each arm has 7 DOF Series Elastic Actuators and features high-strength force-controlled actuators, intrinsic physical compliance, and zero-backlash Harmonic Drive gearheads. The head is a 7 DOF robotic active vision head. Designed for a wide range of expressive postures, it is the ideal platform for researchers interested in human-robot interaction and social robotics. The head system features high resolution FireWire cameras in each eye, integrated DSP controllers, and zero-backlash Harmonic Drive gear-

heads in the neck. Each hand is a fully-contained 5 DOF underactuated hand. It is approximately human size with intrinsic physical compliance and force feedback, making it ideal for researchers interested in dexterous manipulation within human environments. Its underactuated and compliant fingers allow it to robustly power grasp a wide range of everyday object without complex grasp planning. The robot uses the Robot Operating System (ROS), including RVIZ kinematic visualization, URDF descriptions, posture control of all joints, and common sensor interfaces. The robot has ROS features for manipulation, navigation, and human-robot interaction.

The handshake involves two main components of the robot: 1) the arm, and 2) the hand. The robot's arm is composed of seven DOF (see Figure 2): JA0 (Shoulder roll), JA1 (Shoulder pitch), JA2 (Biceps), JA3 (Elbow), JA4 (Wrist roll), JA5 (Wrist pitch), JA6 (Wrist yaw). The robot's hand is composed of three fingers and a thumb (see Figure 2). The three fingers are driven by a tendon which controls their closures. The thumb is driven by a tendon (thumb closure) and a motor (thumb orientation). Thus, five DoF are used to control the fingers and the thumb: JF0-JF1 (Thumb) to JF2-JF3 (Fingers). Encoders are used to measure the tendons positions and the motor angle.

The DOF of both the arm and hand use a joint-impedance controller [18] [19]. It control the joint position and its compliance. By tuning the stiffness parameters, it is possible to make the robot joint feeling like a hard or soft spring, while maintaining control on the desired joint position. The robot's arm and are controlled as follow:

- **Arm:** we assign for each DOF (JA0-JA6) an angle and a stiffness value in order to achieve the required arm configuration (i.e., arm outstretched, see Figure 1). In this study, the stiffness values vary (soft to hard stiffness) according to the investigated conditions while the angles are fixed.
- **Hand:** we assign for each DOF (JF0-JF4) an angle and a stiffness value in order to achieve the required hand configuration (i.e., hand grasping, see Figure 1). In this study, the stiffness values are fixed while the angles (fingers half closed and completely closed) vary according to the investigated conditions. Wide angles lead to apply a high intensity grasping force and small angles lead to apply a low intensity grasping force.

For the MEKA robot, the stiffness of joints is a value between 0 and 1 (i.e., 0 value represents highly compliant; and 1 value represents very high rigidity). The angles of the DOF are set in degrees.

4.2 Conditions

Two main independent variables were considered for this experiment. These two variables will be denoted in the text as: IV1 and IV2. First, the facial expressions of the robot (**IV1**). Three facial expressions were presented to participants, namely: sadness (denoted as '-'), neutral (denoted as '0') and joy (denoted as '+'). The emotions were expressed with the lips display (see Figure 3). The eye orientations and the eyelid opening were not involved in this study.

The second variable corresponds to the haptic behavior of the robot's arm during the handshake behavior (**IV2**). It combines two haptic effects: the stiffness of the movement of the robot's arm and the

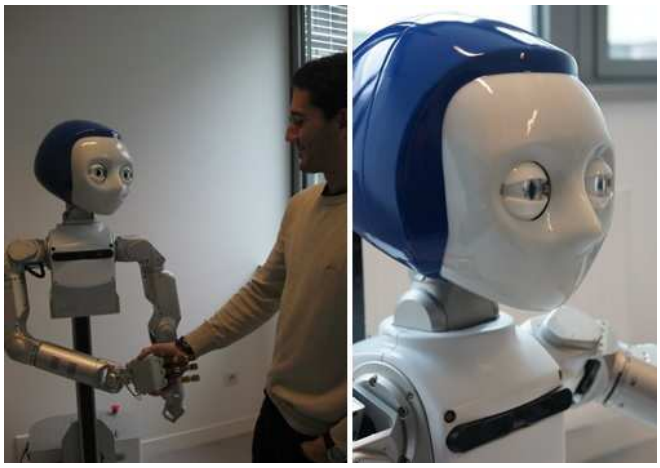


Figure 1: Meka Robot (ENSTA-ParisTech) - an expressive head, humanoid torso with 2 arms, mounted on a mobile base

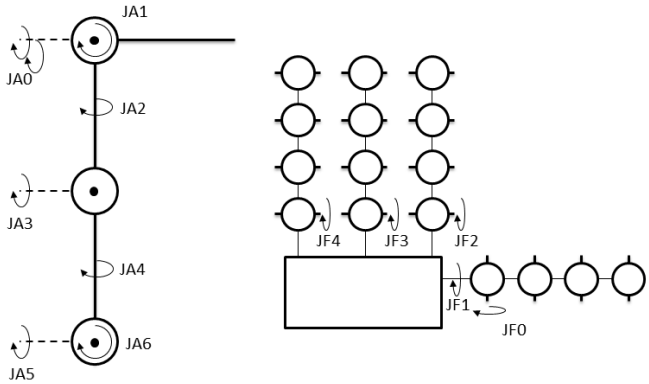
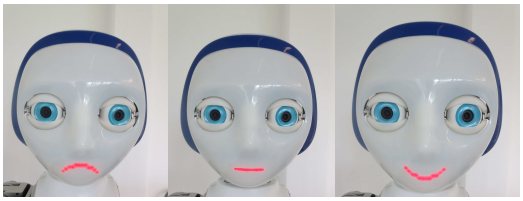


Figure 2: DOF of the robot's arm and hand



(a) (b) (c)

Figure 3: The three Facial Expressions of the robot: (a) sadness ('-'); (b) neutral ('0'); (c) and joy ('+'). Only the lips display was used. The eye orientations and the eyelid opening were not involved in this study.

grasping force of the robot's hand. For the stiffness of the movement of the robot's arm, two values of stiffness were assigned to all DOF (JA0-JA6): high (stiffness value = 1) (denoted as 'R') and low (stiffness value = 0.15) (denoted as 'r'). The angles of the seven DOF were fixed for both low and high stiffness of the movement of the robot's arm (see Figure 1). For the grasping force, two values of angles were assigned to JF0,JF2,JF3 and JF4: high intensity (denoted as 'F') and low intensity (denoted as 'f'). The opening angles of fingers are fixed as follows: wide angles [300,300,300,300], and small angles [160,165,210,240]. JF0 was fixed. The speed of the grasping hand is fixed at 80 deg/second and the stiffness of each tendon was set at 0.5 for both low and high intensity grasping force. Based on these two haptic effects, we presented two haptic behaviors, namely: soft haptic behavior (denoted as 's'), corresponding to the 'fr' configuration, and strong haptic behavior (denoted as 'S'), corresponding to the 'FR' configuration. The other coupling configurations were not investigated in this study.

A summary of the different variables is given in Table 1.

The generation of the haptic expressions follows this protocol:

- step 1: The robot's arm and hand are in neutral configurations: the arm is relaxed and the hand is open.
- step 2: The robot's arm moves to achieve the handshake configuration: the arm is outstretched and the hand is open.
- step 3: When the subject grasps the robot's hand, the robot's hand closes.
- step 4: The subject handshake the robot's hand. The haptic expression is rendered during 5 seconds (see conditions above).
- step 5: After 5 seconds the robot opens its hand and the subject removes his hand.

Hypothesis 3.a: Figure 6 and Figure 7 compare the monomodal ('V' and 'H') and multimodal ('VH') conditions for the evaluation of arousal and dominance respectively. The comparison is carried out for the three visual conditions ('-', '0', '+'), but only the 'S' haptic condition (i.e., when the grasping force is high and the stiffness of movement is high) is considered for this comparison.

Based on these two variables, three main conditions were investigated:

Table 1: The summary of the two independent variables used in the experiment. IV1 - facial expressions: - (sadness), 0 (neutral), + (joy); IV2 - haptic behavior: s (soft haptic behavior), S (strong haptic behavior)

	Visual (V)	Haptic (H)
Variables	IV1 - Facial expressions	IV2 - haptic behavior
Values	-, 0, +	s, S

- **Visual condition (V)**: Only facial expressions of the robot (IV1) are presented to the participants.
- **Haptic condition (H)**: The participants shake the hand of the robot. Only the two haptic behaviors of the robot's arm are presented to participants (IV2). No facial expressions are presented.
- **Visuo-Haptic condition (VH)**: The facial expressions are presented to participants (IV1) while they shake the hand of the robot (IV2). The study had a 3(IV1) x 2(IV2) design. Hence, the robot could manifest joy/sadness/neutral facial expressions and soft/strong haptic behaviors during the handshaking.

4.3 Participants

18 participants (12 males and 6 females aged between 23 and 57 years old) took part in this study. 16 participants were right-handed and 2 participants were left-handed. The participants had no known neurological or physical injury that could affect their haptic sensitivity and their physical behaviour. Participants gave informed consent prior to testing, and the experiment was approved by an institutional internal review board of the laboratory.

4.4 Procedure and Measures

Before participating in the experiment, each participant was asked to complete a questionnaire for determining personal details such as gender, age, educational background, left/right handed, and their computer game joystick playing habits. The experiment starts with a familiarization and training phase. This phase lasts between 15 – 20 minutes as a function of the participant's reaction towards the robot. During this phase, the Meka robot is presented to the participant. The experimenter explains to the participant the handshaking task without giving details about the different visual and haptic variables. Moreover, the experimenter asks the participant to stay put in front of the robot. The robot detects the height of the participant and adjusts its height accordingly with the help of the prismatic lift. The participant is encouraged to look to the robot's head and handshake the robot's hand several times while different visual and haptic variables are played. When the participant seems comfortable enough in the presence of the robot and familiar with the handshaking task the participant is asked to perform the three conditions (i.e., Visual-only; Haptic-only; Visuo-Haptic) in a sequence as part of a predefined scenario. The participant could stop the experiment at any time. In-between conditions, the Visual-only and Haptic-only are randomized and they are played before the Visuo-Haptic condition. Each condition has been played 2 times in a random order. Each participant has been involved in 38 interactions with the robot (visual-only, haptic-only, visuo-haptic). In the Haptic-only and Visuo-Haptic conditions, each handshake lasts for 5 seconds. In the Visual-only condition each emotion lasts 5 seconds. After each interaction the participant is asked to fill-up a

PAD questionnaire so as to evaluate the perceived emotions transmitted by the robot behavior during the interaction. The participant rates the three dimensions of the PAD affective space using a 5-points bipolar Likert scale. The question asked was: "The emotion expressed by the robot seems to be". The possible answers were (on a 5-points Likert scale):

- **M1**: from "very negative" to "very positive" (valence).
- **M2**: from "not arousing" to "very arousing" (arousal).
- **M3**: from "very dominated" to "very dominant" (dominance).

5. EXPERIMENTAL RESULTS

As we don't think the data don't fit the assumptions of an anova, especially normality assumption (evaluation values come from Lickert scales), we carried out Kruskal-Wallis analysis to test the hypothesis and to highlight the differences between monomodal (i.e., Visual-only, Haptic-only) conditions and multimodal condition (i.e., Visuo-Haptic). When differences were highlighted, we complement the Kruskal-Wallis test by performing (follow-up) post hoc test with subsequent non-parametric multiple comparisons, based on function 'kruskalmc' of R package 'pgirmess' [20] that implements Bonferroni-corrected asymptotic normality-based multiple comparisons of all treatments pairs [21].

Hypothesis 1: Figure 4 presents, for the visual conditions ('-', '0', '+'), the evaluation of valence (**M1**), arousal (**M2**) and dominance (**M3**) respectively. The analysis reveals at least one significant difference between the visual conditions in terms of valence evaluation: $\chi^2(2, N = 108) = 86.53$, $p < 0.05$. Subsequent pairwise comparisons between groups indicated that the valence was evaluated significantly more positively with the joy facial expression than with the neutral ($difference = 36.18$) and with the sadness facial expression ($difference = 66.61$). Moreover neutral facial expression was evaluated significantly more positively than the sadness facial expression ($difference = 30.43$) (see Figure 4.a). The analysis reveals also at least one significant difference in terms of arousal evaluation: $\chi^2(2, N = 108) = 7.10$, $p < 0.05$. Subsequent pairwise comparisons indicated that the valence was evaluated significantly more positively with the joy than with the neutral facial expresion ($difference = 18.76$)(see Figure 4.b). However no other significant differences are found between other couples of facial expression. No significant difference is found in terms of the dominance evaluation: $\chi^2(2, N = 108) = 2.85$, $p = 0.24$ (see Figure 4.c). In all cases, the critical difference ($p = 0.05$ corrected for the number of tests) was 17.67.

Hypothesis 2: Figure 5 presents, for the haptic only conditions ('S', 's'), the evaluation of valence (**M1**), arousal (**M2**) and dominance (**M3**) respectively. The analysis reveals at least one significant difference between the haptic conditions in terms of valence evaluation: $\chi^2(3, N = 72) = 14.82$, $p < 0.05$. Subsequent pairwise comparisons indicated that the valence was evaluated significantly more positively with strong (S) than with soft (s) haptic behavior ($difference = 29.93$)(see Figure 5.a). The analysis reveals also at least one significant difference between the haptic conditions in terms of arousal evaluation: $\chi^2(3, N = 72) = 14.99$, $p < 0.05$. Subsequent pairwise comparisons indicated that the arousal was evaluated significantly differently between the strong (S) condition than the soft (s) one ($difference = 35.55$) (see Figure 5.b). Finally the analysis reveals at least one difference between the haptic conditions in terms of dominance evaluation, $\chi^(3, N = 72) = 34.1$, $p <$

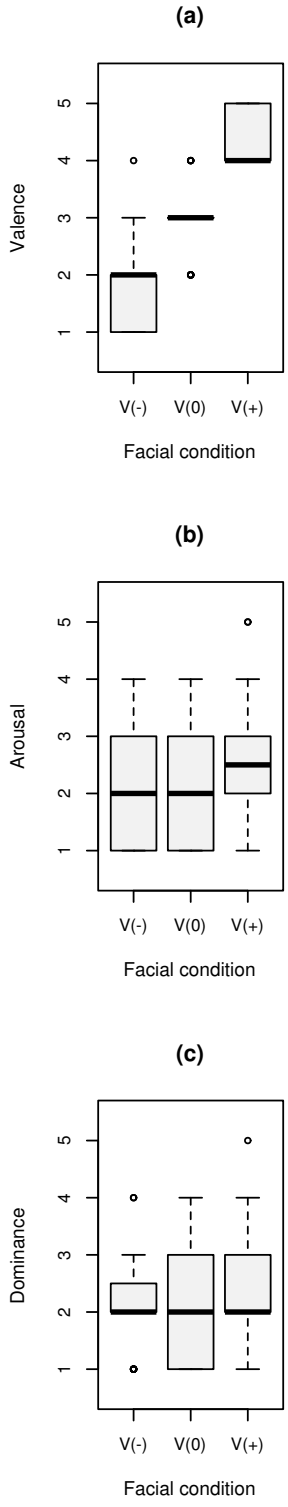


Figure 4: Results of the visual-only conditions ('-', '0', '+'): (a) presents the evaluation of valence (**M1**), (b) presents the evaluation of arousal (**M2**), (c) presents the evaluation of dominance (**M3**). Each bar includes a median value and a box from second quartile (0.25) to third one (0.75) and a whisker, which extends to a maximum of 1.5 inter-quartile distance and circles for outliers.

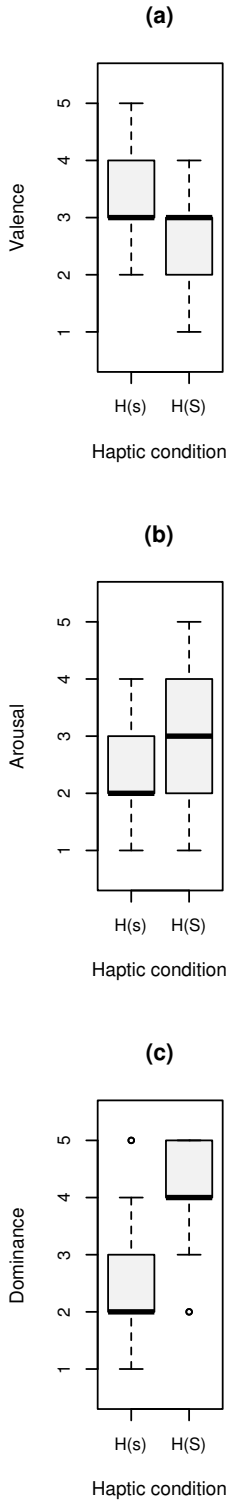


Figure 5: Results of the haptic-only conditions ('s', 'S'): (a) presents the evaluation of valence (**M1**), (b) presents the evaluation of arousal (**M2**), (c) presents the evaluation of dominance (**M3**).

0.05. Subsequent pairwise comparisons indicated that the dominance was evaluated significantly differently between the strong (S) condition than the soft (s) one ($difference = 55.87$) (see Figure 5.c). In all cases, the critical difference ($p = 0.05$ corrected for the number of tests) was 25.94.

Hypothesis 3: Figure 6 and Figure 7 compare the monomodal ('V' and 'H') and multimodal ('VH') conditions for the evaluation of arousal and dominance respectively.

Hypothesis 3.a: Concerning the arousal evaluation, a significant difference is highlighted between V(-) facial condition and the VH condition: $\chi^2(4, N = 540) = 30.79$, $p < 0.05$. Follow-up tests showed that the arousal was significantly evaluated with higher value in the multimodal expression with strong (S) haptic behavior than in the monomodal visual only negative expression ($difference = 51.72$) (see Figure 6.a). A significant difference is highlighted between the V(0) facial condition and the VH condition: $\chi^2(4, N = 540) = 44.62$, $p < 0.05$. Follow-up tests showed that the arousal was significantly evaluated with higher value in the multimodal expression with strong (S) haptic behavior than in the monomodal visual only neutral expression ($difference = 73.89$) (see Figure 6.b). A significant difference is found between the V(+) facial condition and the VH condition: $\chi^2(4, N = 540) = 14.95$, $p < 0.05$. Follow-up tests showed that the arousal was significantly evaluated with higher value in the multimodal expression with strong (S) haptic behavior than in the monomodal visual only positive expression ($difference = 39.64$) (see Figure 6.c).

Concerning the dominance emotional factor, a significant difference is highlighted between the facial negative expression evaluation and the multimodal expression: $\chi^2(4, N = 540) = 42.98$, $p < 0.05$. Follow-up tests showed that the dominance was significantly evaluated with higher value in the multimodal expression with strong (S) haptic behavior than in the monomodal visual only negative expression ($difference = 59.54$) (see Figure 7.a). A significant difference is found between the facial neutral expression evaluation and the multimodal expression (Figure 7.b): $\chi^2(4, N = 540) = 54.89$, $p < 0.05$. Follow-up tests showed that the dominance was significantly evaluated with higher value in the multimodal expression with strong (S) haptic behavior than in the monomodal visual only neutral expression ($difference = 77.94$) (see Figure 7.b). A significant difference is highlighted between the facial positive expression evaluation and the multimodal expression (Figure 7.c): $\chi^2(4, N = 540) = 50.23$, $p < 0.05$. Follow-up tests showed that the dominance was significantly evaluated with higher value in the multimodal expression with strong (S) haptic behavior than in the monomodal visual only positive expression ($difference = 72.83$) (see Figure 7.c).

In all cases, the critical difference ($p = 0.05$ corrected for the number of tests) was 34.47.

Hypothesis 3.b: Concerning the arousal (Figure 6), no significant difference is highlighted between the 's' haptic condition (i.e., when the grasping force is low and the stiffness of movement is low) and the multimodal condition: $\chi^2(3, N = 288) = 5.01$, $p = 0.17$. No significant difference is highlighted between the 'S' haptic condition (i.e., when the grasping force is high and stiffness of movement is high) and the multimodal expression: $\chi^2(3, N = 288) = 1.19$, $p = 0.75$.

The analysis reveals some differences in terms of dominance eval-

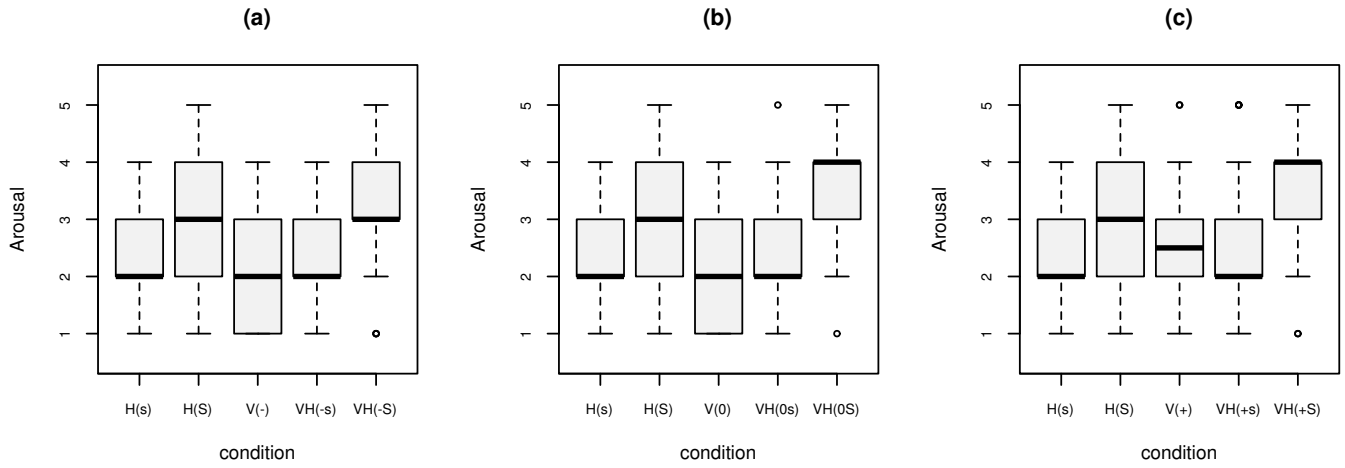


Figure 6: Results comparing the evaluation of arousal (**M2**) between the monomodal ('V', 'H') and multimodal conditions ('VH'): (a) corresponds to sadness facial expression ('-'), (b) corresponds to neutral facial expression ('0'), (c) corresponds to joy facial expression ('+').

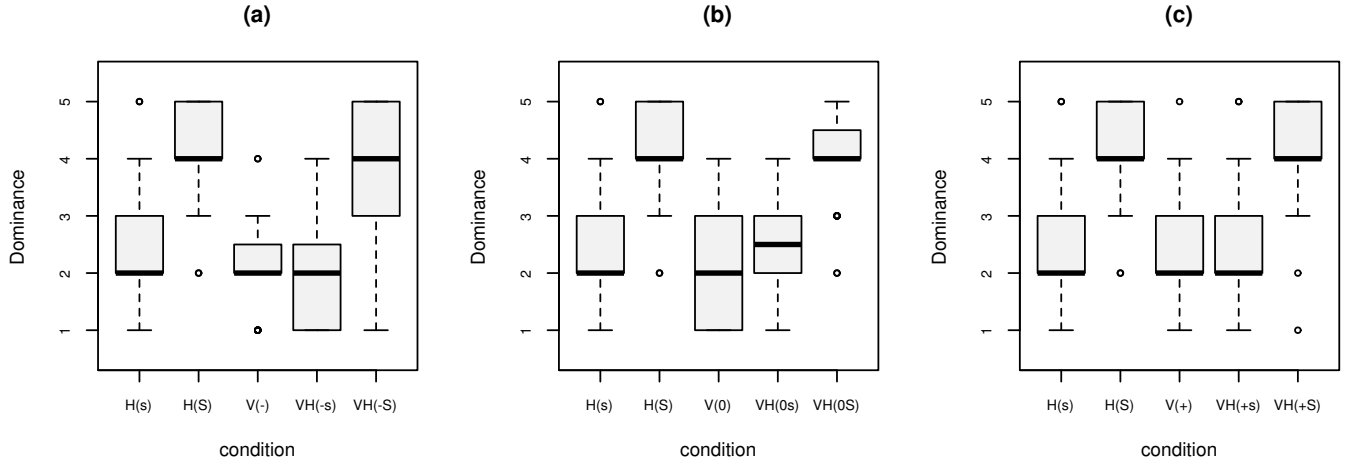


Figure 7: Results comparing the evaluation of dominance (**M3**) between the monomodal ('V', 'H') and multimodal conditions ('VH'): (a) corresponds to sadness facial expression ('-'), (b) corresponds to neutral facial expression ('0'), (c) corresponds to joy facial expression ('+').

uation (Figure 7). Indeed, significant difference is highlighted between the 's' haptic only condition and the corresponding multimodal condition: $\chi^2(3, N = 288) = 8.44$, $p < 0.05$. However, follow-up test is not able to point out any significant difference when comparing the conditions from each other. No significant difference is revealed between the 'S' haptic only condition and the multimodal expression: $\chi^2(3, N = 288) = 5.7543$, $p = 0.12$.

6. DISCUSSION

Visual feedback: Based on the results of the present study, **H1** is partially validated. Indeed only valence is significantly well discriminated. Therefore the results related to the visual condition showed that participants exploit well the facial cue (i.e., lip display) to discriminate the valence and arousal dimensions of the emotions expressed by the robot. This is consistent with other studies investigation the same issue in psychology [4, 22]. However, we observed that participants have difficulties to discriminate the dominance dimension. This is due to the limit of the facial cue (i.e., lip display) to support this emotional dimension.

Haptic feedback: Based on the results of the present study, **H2** is validated for each dimension. Therefore the results related to the haptic condition showed that participants discriminate well the dominance and the arousal dimensions of the haptic behaviours presenting low and high values for grasping force and stiffness of movement. Concerning the arousal dimension, several works in psychology and haptics for human-machine interfaces highlighted the effect of haptic feedback for the perception of this dimension [2]. However, these works investigate active haptic feedbacks where a movement is applied on the user's body. For instance, Gaffary et al. [23] showed that applying a movement with an important amplitude on the user's hand increases the perception of arousal. The results of our study highlighted the effect of a passive haptic feedback, i.e., without generating a movement, on the perception of the arousal. High values for grasping force and joint stiffness lead to the increase of the perceived arousal although the robotic arm do not generate movement. Concerning the perception of dominance, researches in psychology highlighted the role of interpersonal touch to convey this dimension [24]. However, they have not identify the physical parameters influencing the perception of this dimension. For human-robot collaborative tasks, Groten et al. [14] showed that the grasping stiffness exerted by the robot on the shared object influences the perception of the dominance. Our results showed that similarly to the arousal dimension, the passive haptic feedback applied on the user's hand influences the perception of the robot's dominance. High values for grasping force and joint stiffness increase the level of perceived dominance.

In order to identify the role of two haptic parameters for the perception of the different dimensions, complementary analyses are planned.

Multimodal feedback: Based on the results of the present study **H3.a** is validated. However according to the present results, **H3.b** is rejected. The results related to the multimodal condition clearly show that introducing high values for grasping force and joint stiffness leads, for the three investigated emotions, to the increase of the perceived arousal and dominance compared to the visual-only condition. Since we do not observe a real difference for the perception of dominance and arousal between the multimodal condition and the haptic condition, we can assume that the perception of these two dimensions are mainly influenced and increased by the haptic feedback under the multimodal condition. Thus, the haptic channel complements the visual channel, which mainly supports the perception of the valence, for the perception of emotions. The combination of sensory channels to convey complementary dimensions of emotions was observed in several psychology researches. For instance, Betsy et al. [25] observed that for some categories of emotions the postural configurations convey social-status components while facial expressions convey survival components. The authors of [26] suggest that people weight the emotional signals from different sensory channels and then combine them in an optimal fashion. Concerning the role of the different sensory channels, the works of Major [24] clearly highlighted the effect of touch to convey the dominance between partners. In addition, several works highlighted the role of the facial expression for the evaluation of the emotional valence of some emotions such as joy and sadness [22], [25]. We assume that the arousal might be supported by both haptic and visual channels. However, the visio-haptic coupling clearly leads to the increase of the perception of the intensity of this dimension. A thorough analysis of the results with complementary experiments are planned in order to establish the relationships between the two investigated haptic parameters and the perception of the three dimensions of emotions in a multimodal configuration.

7. CONCLUSIONS

Robots are more and more present in our daily lives. In human-robot interaction, a social intelligent robot should be capable of understanding the context of interaction with the human so as to behave in a proper manner by following some social rules. This paper focuses on the haptic affective social interaction during a greeting handshaking between the human and the robot. We investigated how the haptic feedback influences the perception of the dimensions of emotions, namely: arousal and dominance. The results show that the facial cue conveys well the arousal and valence but not the dominance. The latter is well conveyed during the haptic interaction. In fact, participants discriminate well the dominance dimension of haptic behaviours presenting low and high values for grasping force and joint stiffness. This leads, in the multimodal configuration, to a good discrimination of the three dimensions of emotions. Participants combines both visual and haptic cues to perceive the different dimensions.

In order to understand how participants integrate the different sensory cues in order to perceive emotions, future studies are planned. Moreover, it would be interesting to investigate the effect of other haptic feedback, such as tactile and force feedback, on the perception of emotions.

Acknowledgment

This work is supported by the French National Research Agency (ANR) through Chaire d'Excellence program 2009 (Human-Robot Interaction for Assistive Applications) designated to Prof. Adriana TAPUS. We would like to thank Vincent Munsch for his hard work and his involvement in this project.

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