Emotional User Experience of Innovative Human-Computer Interactions: A Multi-Component Approach

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Abstract

Emotions are a relevant indicator of users' acceptance of technologies. Despite users' subjective feeling being traditionally examined with categorical labels, the Component Process Model suggests that the cognitive and motivational component can also be examined in user experience studies. This study focuses on emotions using innovative non-tactile Human Computer Interactions to perform different tasks. Results revealed that cognitive and motivational components of emotions are decisive to confirm or to infirm the self-reported subjective feeling. More precisely, non-tactile controllers triggered significantly higher cognitive appraisals than the tactile controller. These non-tactile controllers also trigger significantly higher readiness to approach and to avoid than the tactile controller, depending on the type of controller used and on its application. The innovativeness of the controller does not necessarily involve positive emotions and needs to be situated in a specific context of use. This analysis show how user experience testing for product development could gain in investigating the additional components of users' emotional experience.

Keywords: emotion, technology acceptance, innovation, user experience
Word count: 5628

Technical advances in human motion detection have facilitated the design of richer Human-Computer Interactions –or HCI– (Rautaray & Agrawal, 2015). Among these technologies, tactile detection systems are now common to all smartphone and tablet users. They are useful technologies that provide important affordances to users for two-dimension (2D) HCI (Magallanes et al., 2012). Increasingly "natural" interactions continue to be developed to improve users' experience with the technology (e.g., Dalsgaard & Halskov, 2012; Hinckley & Song, 2011). One promising technology is the development of non-tactile HCI controllers that measure interactions in three directions (i.e., x, y and z in a dimensional space, here after called 3D) that offer users new opportunities to control and to navigate in systems (König et al., 2010).

With the development of Microsoft's Kinect (Zhang, 2012), body-based interaction technologies shape new ways to interact with computers with 3D sensors (Geisler et al., 2007).

As accurate as tactile interactions, non-tactile controllers free users from the constraints of a surface by providing a 3D space in which to control computer applications through the capture of users' hand and forearm movements (Freitag et al., 2012). Technologies have been created by several companies such as GestIC, Ultraleap, Mgestyk, Elliptic Labs and Isorg that accurately detect users' hand movements in order to control computers (Garber, 2013).

Literature review

To anticipate the commercial success of HCI, User Experience researchers have conducted extensive studies in order to evaluate users' perceptions (e.g., Bruseberg & McDonagh-Philp, 2001; Kujala et al., 2011). Etymologically, the concept of User Experience corresponds to the experience of the person who interacts with and benefits from a product or a service. It was first employed to investigate the use of chemicals and electrical equipment (Nixon, 1965) but it has become widespread with the development of computer interfaces (Lallemand et al., 2015). According to the User Experience principle, if the experience is sufficiently satisfactory, then the probability of a first / new use will be all the greater (Sward & Macarthur, 2007). Among these studies, understanding users' acceptance of any given technology appears to be a decisive criterion. User acceptance of technologies is defined as the probability that a technology will be embraced by a user in a given context (Donnelly, 1970). More precisely, technology acceptance is a psychological process through which a product or service is successfully adopted by the user (Turner, 2005). Thus, investigating the products or services' characteristics that facilitate technology acceptance is essential to improve their adoption in a market segment (Rogers, 2010). This prognosis can be applied after the use of the technology, but also on users' expectations via written or verbal descriptions (e.g., Hoeffler, 2003; Olshavsky & Spreng, 1996), in addition to visual representations (e.g., Blijlevens et al., 2012; Blythe, 1999; Leder & Carbon, 2005; Lee et al., 2011; Ziamou, 2002). Investigating technology acceptance means to empirically estimate this probability with

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users' feedback on their integration of instrumental and non-instrumental characteristics. Thus, the more a piece of technology's characteristics are assessed positively, the more users will accept it (Alexandre et al., 2018). This is also the case for non-tactile controllers. They require user experience studies to evaluate users' emotions and to predict their intention to use these technologies.

Emotions as Predictor of Technology Acceptance

Historically, the consideration of emotions comes very late in the design models that aim to predict the intention to use technologies. For instance, the Technology Acceptance Model (TAM, Davis, 1985, 1989) takes a rational perspective of users' decision-making and behaviors by focusing on the perceived usefulness and ease of use. Similarly, the Unified Theory of Acceptance and Use of Technology (UTAUT, Venkatesh et al., 2003, 2012) estimates that performance and effort expectancy, as well as the social influence are predicting the intention to use a technology. However, users' decision-making and behaviors seem to be influenced by another variable: user emotion (Imbir, 2016). Indeed, emotion appears to be crucial in explaining consumer behavior in general (Hirschman & Holbrook, 1982). Studies have shown that behaviors such as playfulness, the desire to approach and to use new products, are triggered by positive emotions (Fredrickson, 1998, 2001; Watson et al., 1999). In addition, positive emotions stimulate exploratory behavior, and would lead users to experiment in new ways to perform actions (Isen et al., 1987; Kahn & Isen, 1993; Partala & Saari, 2015). Emotions influence both the way users are perceiving a technology and how they are interacting with it. For example, Igbaria et al. (1994) show that users' satisfaction in using a computer laptop for work related tasks was better predicted by amusement than by utility. Thus, the more users feel positive and experience intense emotions, the greater the probability that they will use the technology again. Given the non-rational nature of the user's technology acceptance process, the concept of emotional user experience aims to focus on the importance of emotion felt when using a product or service. Primarily used in the context of the Kansei engineering approach (Mohd Lokman, 2009; Song et al., 2009), the emotional user experience framework was then applied to various HCI and technologies (Jokinen, 2015; Saariluoma & Jokinen, 2014; Yoo & Ju, 2018).

In order to highlight the main concepts that could be taken into account in a model to analyze the user experience, a literature review (Park et al., 2013) focused on 127 studies to identify the main predictors of the user experience. Three predictors appear to be predominant: the user's emotions, perceived values, and perceived usability (Law et al., 2014). In a second literature review, Bargas-Avila and Hornbæk (2011) selected 51 articles published between 2005 and 2009. This review of literature highlights the use of concepts related to the internal state of the user. Thus, concepts such as affect, emotion, feeling, pleasure, fun, amusement, or frustration are used as predictors to explain user reactions. However, given the diversity of the emotion related concept used, most of them are not sufficient to describe the complexity of the emotion experienced (Edwardson, 1998; Lindgaard & Dudek, 2003). For instance, the models of acceptability which only integrate the concept of satisfaction cannot account for the diversity of emotions (Wixom & Todd, 2005). According to Nielsen (1994), the influence of technologies users' emotional reactions can be summarized with the following question: is the product or service triggering an experience positive enough for the user to be motivated in interacting again with the product or service? Consequently, the willingness to use a product or a service can be seen as the result of its ability to trigger positive emotions to users (Martin et al., 2008).

Components of Emotions in Human-Computer Interactions

Scherer (2001) defines emotion as "an episode of interrelated, synchronized changes in the states of all or most of the five organismic subsystems in response to the evaluation of an external or internal stimulus event as relevant to major concerns of the organism" (p. 93). These five subsystems, also called components, include cognitive appraisals, physiological responses, motor expressions, motivational changes, and subjective labeling.

The cognitive component is a series of appraisals that detects and assesses the significance of the characteristics of a trigger event to an individual (Moors et al., 2013). Scherer (1984) proposes a sequence of four appraisals applied to each trigger event: relevance of the event for the individual, implications to immediate or long-term goals, possibilities to adjust to these consequences, and significance for an individual's social norms. In the context of technology acceptance, these appraisals can be studied through the perception of stimulus features. Thus, the way a technology is appraised in term of innovativeness (Moreau et al., 2001), originality (Campbell & Goodstein, 2001), and attractiveness (Mathwick et al., 2001; Tsikriktsis, 2002) during users' first interactions will determine how relevant the technology is. The emotional response depends on the perceived relevance of a technology (Aue et al., 2007). Consequently, if a technology is appraised as being innovative, original, and attractive, the probability that it will trigger a positive emotion, and thus result in acceptance, will be higher.

The physiological component corresponds to the regulation of autonomic systems during an emotional experience such as the cardiovascular system, the respiratory system or the thermoregulatory system. The expressive component is responsible for the verbal and non-verbal communication of emotions through mainly vocal, facial and postural expressions.

The motivational component prepares individuals to respond appropriately to the stimulus that triggered it (Scherer, 1984). For Frijda (1986), this component consists in various action readiness states that represent individuals' willingness to improve, to maintain, or to change their existing relationship with the trigger event. Frijda (1987) identifies the main basic "modes" of action readiness, the most important of which are readiness to approach and to avoid the trigger event. As users' interactions with a technology involve acting on this technology, action readiness measures could be relevant indicators to predict new uses. Indeed, users' approach of a technology would indicate a willingness to maintain and to reiterate interactions. On the contrary, users' avoidance would indicate a willingness to interrupt current interactions and to dismiss any future interactions. By studying different types of mobile phones, Schoen and Crilly (2012) reveal that measuring readiness to approach or to avoid them predicts future choices of individuals. Therefore, if a technology triggers readiness to approach and does not trigger readiness to avoid, it is possible to expect that the technology will be used again (Carver & White, 1994).

The subjective component allows individuals to have a conscious access to the processes involved in the other component. It allows individuals to produce a coherent experience and to label it. However, this subjective component does not quite match the information perceived, as consciousness can also rebuild the emotion as a result of the potential imperfections of memory (Scherer, 2005). This access is used by individuals to regulate or to adapt their emotional experience to the situation.

The Component Process Model illustrates how these component are related (Figure 1, see Scherer, 2009b). According to this model, the event is appraised according to several criteria or stimulus evaluation checks which lead to specific physiological, expressive and motivational patterns (Scherer, 1984). Then, cognitive appraisals, physiological responses, motor expression, and motivational changes are implicitly used to create the conscious subjective labeling of the emotion felt.

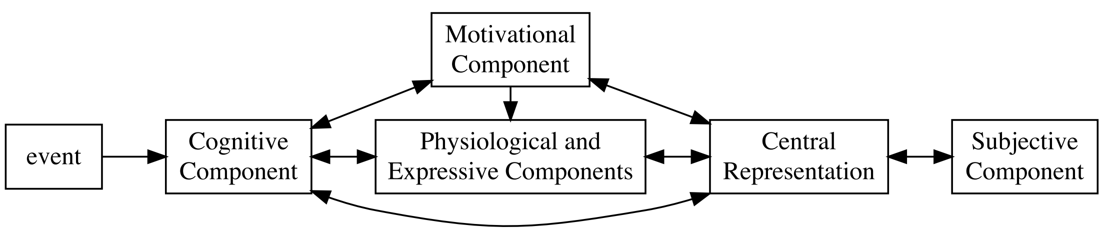

Figure 1

Component process model of emotions adapted from Scherer (2009a).

In order to show the influence of the user experience on the cognitive, motivational and subjective component of emotions, we choose to investigate the use of non-tactile controllers: a non-tactile 2D controller and a non-tactile 3D controller. Regarding the subjective component of emotions, we expect that users will self-report more positive and more intense experiences when using a non-tactile controller –either 2D (hypothesis $H1_a$) or 3D (hypothesis $H1_b$)– compared to a conventional controller. Additionally, regarding the cognitive component, we expect a non-tactile controller –either 2D (hypothesis $H2_a$) or 3D (hypothesis $H2_b$)– to be perceived by users as more innovative, more attractive and more original when using a conventional controller. Finally, regarding the motivational component, we expect that users will self-report more readiness to approach and less readiness to avoid a non-tactile controller –either 2D (hypothesis $H3_a$) or 3D (hypothesis $H3_b$)– than a conventional controller.

Method

In order to test these hypotheses, an experimental design has been adopted. Participants were recruited to use a controller among three possible controllers varying in term of innovativeness. Different tasks were used in order to control for the influence of the task on emotions experienced by users.

Participants

For this experiment 208 students were recruited among social science under- and post-graduates through advertising (31 males and 177 females, age: $M = 20.7$, $SD = 2.9$). They received a course credit for their participation. After a description of the general aims, participants agreed and signed the experiment consent form. The data collected are fully anonymous. To insure the ethical treatment of participants and their data, the protocol of the experiment was approved by Grenoble Alps University representatives.

Material

In order to evaluate HCI in different contexts, participants were randomly assigned to use either a mapping application (task 1) or a skill based game (task 2). Their interaction mode was also randomly allocated with one of the following controller: a tactile 2D controller (control group), a non-tactile 2D controller (experimental group 1), or a non-tactile 3D controller (experimental group 2). After their task, participants' emotions were measured through the cognitive component, the motivational component and the subjective component.

Tasks

To evaluate the influence of the controller used on users' emotions it is essential to limit the influence of other variables susceptible to trigger emotions. In addition to the emotion triggered by the controller itself, emotions can be triggered by the task performed with the controller. Some tasks are enjoyable or thrilling while others can be frustrating or boring. By analyzing more than one task, we are restricting the influence of the task in our analyses. Thus, two tasks were compared in our experimental design. As a result, two tasks were compared in this study. The participant had to use either a mapping application (task 1) or a skill based game (task 2). The mapping application was configured to display the map and the satellite view of a city at a 1:200 resolution. Participants could move only in two directions: north-south and east-west by moving their hand on the controlling device (control group) or over it (experimental group 1 and 2). The task of the participants was to find some specific places on the map. In the skill based game, participants controlled horizontal bars with their hands on the controlling device (control group) or over it (experimental group 1 and 2). The bar rotated around its central axis. If the participants moved their hand/cursor from one side or the other, the bar rotates in the same direction. A ball was balanced on this bar and coins appeared randomly. The task of the participants was to quickly get the coins using the ball without the ball falling from the bar.

The tasks performed by the participants are distinguished by two main criteria. The first distinction is linked to the task itself. The skill based game involves a much bigger issue of performance and failure than the mapping application task. The second distinction relates to the interaction with the device since the skill based game requires only a use of the horizontal dimension of space while the mapping application task involves both the horizontal dimension and the depth in the user interaction space.

Controllers

To perform their specific task, participants were assigned to one specific controller to perform a task: a tactile 2D (control group), a non-tactile 2D (experimental group 1) or non-tactile 3D (experimental group 2) controller. In the control group, participants used a Dell remote computer mouse. In the first experimental group, participants used a non-tactile 2D controller developed by Isorg. This controller is made of a hexagonal surface equipped with 100 photo-detectors measuring user's movements on a 2D space (x and y axes). In the second experimental group, participants used a non-tactile 3D controller developed by Ultraleap. This non-tactile 3D controller is made of three cameras that detect hand movements on a 3D space (x, y, and z axes).

As previously mentioned, the non-tactile 2D controller and the non-tactile 3D controller both work on principles of optical motion capture, however the system they use diverges. The differences and commonalities of these two non-tactile controller are presented in Table 1.

Table 1

Technical features of the 2D and 3D non-tactile controllers.

Feature	Non-tactile 2D controller	Non-tactile 3D controller
Sensor type	Light intensity	Video recording
Number of sensors	100	3
Capture area	From 0 to 50cm above the sensors	From 0 to 50cm in front of the cameras
Detection space	x and y	x, y, and z

Measures

The subjective, cognitive and motivational components of emotion were measured separately with self-reports (see Supplementary Table 1). To evaluate the influence of user interactions on the subjective component of emotions, participants were asked to assess their emotion according to two dimensions: valence and arousal (Mazaheri et al., 2010). The valence scale is made of 2 items and the arousal scale is made of 4 items.

The cognitive component of emotions is evaluated with 4-item scales measuring the users' perception of their controllers' innovativeness (Moreau et al., 2001), 3-item scales measuring the perceived attractiveness (Mathwick et al., 2001; Tsikriktsis, 2002), and 4-item scales measuring the perceived originality (Campbell & Goodstein, 2001). Perceived innovativeness and perceived attractiveness of controllers were measured by users' agreement with sentences on Likert scales. The perceived originality was assessed with semantic differential items.

The motivational components of emotions were explicitly measured with two items evaluating participants' approach and two items evaluating participants' avoidance of the controller (Donovan et al., 1994). These items aimed to evaluate the motivation of participants to use or not use a given controller in their daily life.

Finally, a scale measuring participant openness to innovation has also been administered (Roehrich, 2004). This scale is made of 8 items and was used to ensure the equivalence between groups regarding their profile.

Procedure

Participants were recruited to perform a study about "user experience." They were welcomed into the experimental room and placed in front of a DELL Latitude E5520 computer connected to an HCI controller (i.e., tactile 2D or non-tactile 2D or non-tactile 3D) and setup with a specific task (i.e., mapping application or skill based game). After agreeing and signing the consent form, participants had a brief presentation of the task to perform and how to use the controller within this task. Then, participants had 5 minutes to freely practice the use of the controller. Once the practice finished, participants were asked to reach certain targets in a specific time frame (i.e., identify some geographic zones with the mapping application or collect a certain number of coins with the skill based game). Finally, participants were asked to fill out the questionnaires. At the end of the experiment participants were thanked and provided with credit for their participation. Overall, the experiment lasted 30 minutes.

Data analysis

The influence of controllers used on the cognitive, motivational and subjective components of user's emotions is evaluated using a co-variance based structural equation model (SEM) between the scales items and their corresponding latent component. This SEM was performed with the lavaan R package which uses Maximum Likelihood estimations (Rosseel, 2012). Despite being more sensitive to small sample size, the Maximum Likelihood estimation was used for its consistency compared to alternative estimations such as Partial Least Squares or Generalized Least Squares for example (Carroll & Ruppert, 1982; Hair et al., 2019).

The latent cognitive component is related to each item from perceived innovativeness, perceived originality and perceived attractivity scales as shown in Equation (1); the latent motivational component is related to each item from the approach and avoidance scales as shown in Equation (2); and the latent subjective component is related to each items from valence and arousal scales as shown in Equation (3).

$$Cognitive.Component = in_1 + ... + in_4 + or_1 + ... + or_4 + at_1 + ... + at_3 + \epsilon_i \tag{1}$$

$$Motivational.Component = ap_1 + ap_2 + av_2 + av_1 + \epsilon_i \tag{2}$$

$$Subjective.Component = ev_1 + ... + ev_4 + ea_1 + ea_2 + \epsilon_i \tag{3}$$

where $in_1, ..., in_4$ are the items from perceived innovativeness scale, $or_1, ..., or_4$ the items from perceived originality scale, $at_1, ..., at_3$ the items from perceived attractivity scale, ap_1 and ap_2 the items from the approach scale, av_1 and av_2 the items from the avoidance scale, $ev_1, ..., ev_4$ the items form the valence scale and ea_1 and ea_2 the items from the arousal scale. The model performed includes all the combinations for the residual covariance between items from a same scale and no covariance between items from different scales.

To test our hypotheses, the SEM includes linear regression models between each of the components with controller type and task as predictors. This analysis is using contrasts to oppose the control device to the non-tactile 2D controller (C1) on the one hand and to the non-tactile 3D controller (C2) on the other hand. The influence of the task is also taken into account as a model predictor as shown in Equation (4).

$$Component_k = b_0 + b_1.T + b_2.C1 + b_3.C2 + \epsilon_i \tag{4}$$

where k is one of the cognitive, motivational and subjective component. The task (T) is coded as -1 for the mapping application and 1 for the skill based game. Sum contrasts are applied to the comparison between control and non-tactile 2D controllers (C1) and between control and non-tactile 3D controllers (C2). The weights of the contrasts are shown in the matrix (5).

$$\begin{array}{l} \\ task\,1 \cdot control \\ task\,1 \cdot non\,tactile\,2D \\ task\,1 \cdot non\,tactile\,3D \\ task\,2 \cdot control \\ task\,2 \cdot non\,tactile\,2D \\ task\,2 \cdot non\,tactile\,3D \end{array} \begin{array}{c} \begin{array}{ccc} T & C1 & C2 \end{array} \\ \begin{pmatrix} -1 & -1 & -1 \\ -1 & 1 & 0 \\ -1 & 0 & 1 \\ 1 & -1 & -1 \\ 1 & 1 & 0 \\ 1 & 0 & 1 \end{pmatrix} \end{array} \tag{5}$$

Although they are providing similar results, the SEM approach was preferred to a MANOVA for its ability to take into account all the latent components simultaneously and therefore to test the hypothesis with a unique model (Breitsohl, 2019; Cole et al., 1993; Dimitrov, 2006). Moreover, with a sample of 208 participants evaluated on a 218 degree of freedom model and using a 0.8 statistical power and 0.05 significance level, the estimated effect size is 0.28 which corresponds to a medium effect and hence remains in the range of the effects obtained in technology acceptance studies (Dwivedi et al., 2019; Khechine et al., 2016).

Results

Before carrying out the analysis, we studied the apparent homogeneity of participants' openness to innovation (Roehrich, 2004) according the three conditions. As expected, the average openness to innovation score appears to be similar for each condition (Control: $M = 3.95, SD = 0.79$; Non-tactile 2D: $M = 3.36, SD = 1.01$; Non-tactile 3D: $M = 3.75, SD = 0.93$).

Reliability of self-reported scales

Cronbach's αs show a good correlation between items for all the component scales: subjective component (Valence: $\alpha = 0.86$; Arousal: $\alpha = 0.73$), cognitive component (Perceived Innovativeness: $\alpha = 0.83$; Perceived Originality: $\alpha = 0.91$; Perceived Attractivity : $\alpha = 0.9$) and motivational component (Approach: $\alpha = 0.89$; Avoidance: $\alpha = 0.91$). These results lead us to conclude that our scales accurately measure single dimensions.

Influence of the controllers according the task performed on the emotion component

First, the model proved a reasonably good fit to the data, using both Comparative Fit Index and Tucker-Lewis Index ($CFI = 0.92$ and $TLI = 0.90$) and where fit was evaluated in terms of the standard measures of Root Mean Squared Error of Approximation ($RMSE = 0.08$, CI[0.07,0.09]). As expected the structural equation model shows a significant contribution of all the items to their corresponding latent component (ps $< .001$) which indicates the good-fitness of the component factorial structure (Figure 2, see Supplementary Table 1 for standardized estimates table). The overall model shows a significant influence of the predictors on the three latent components ($\chi^2(216) = 504.16, p < .001$).

The significant covariation of the three components reveals the relevance of the tested structural equation model (Cog-Mot: $b = 0.35, CI[0.2, 0.49], z = 4.68, p < .001$; Cog-Sub: $b = 0.49, CI[0.35, 0.64], z = 6.8, p < .001$; Sub-Mot: $b = 0.94, CI[0.84, 1.04], z = 18.19, p < .001$).

Regarding the hypotheses, no significant difference has been found between the control group and the non-tactile 2D controller on the subjective component of emotions ($H1_a$: $b = -0.16, CI[-0.33, 0], z = -1.98, p = .050$). However, the non-tactile 2D controller triggers significantly higher cognitive appraisal regarding its innovative relevance ($H2_a$: $b = 0.44, CI[0.34, 0.54], z = 8.92, p < .001$). Regarding the motivational component of user's emotions, the group of participants using the non-tactile 2D controller reported on average less willingness to approach and more willingness to avoid the controller than participant using the tactile 2D controller ($H3_a$: $b = -0.18, CI[-0.34, -0.03], z = -2.34, p = .020$).

Contrastingly, the comparison between the control group and the use of the non-tactile 3D controller reveals a significant increase on the subjective, motivational and cognitive component of emotions ($H1_b$: $b = 0.47, CI[0.32, 0.61], z = 6.23, p < .001$; $H2_b$: $b = 0.44, CI[0.34, 0.54], z = 8.86, p < .001$; $H3_b$: $b = 0.41, CI[0.27, 0.56], z = 5.62, p < .001$).

The results of hypothesis testing for each component is summarized in Table 2.

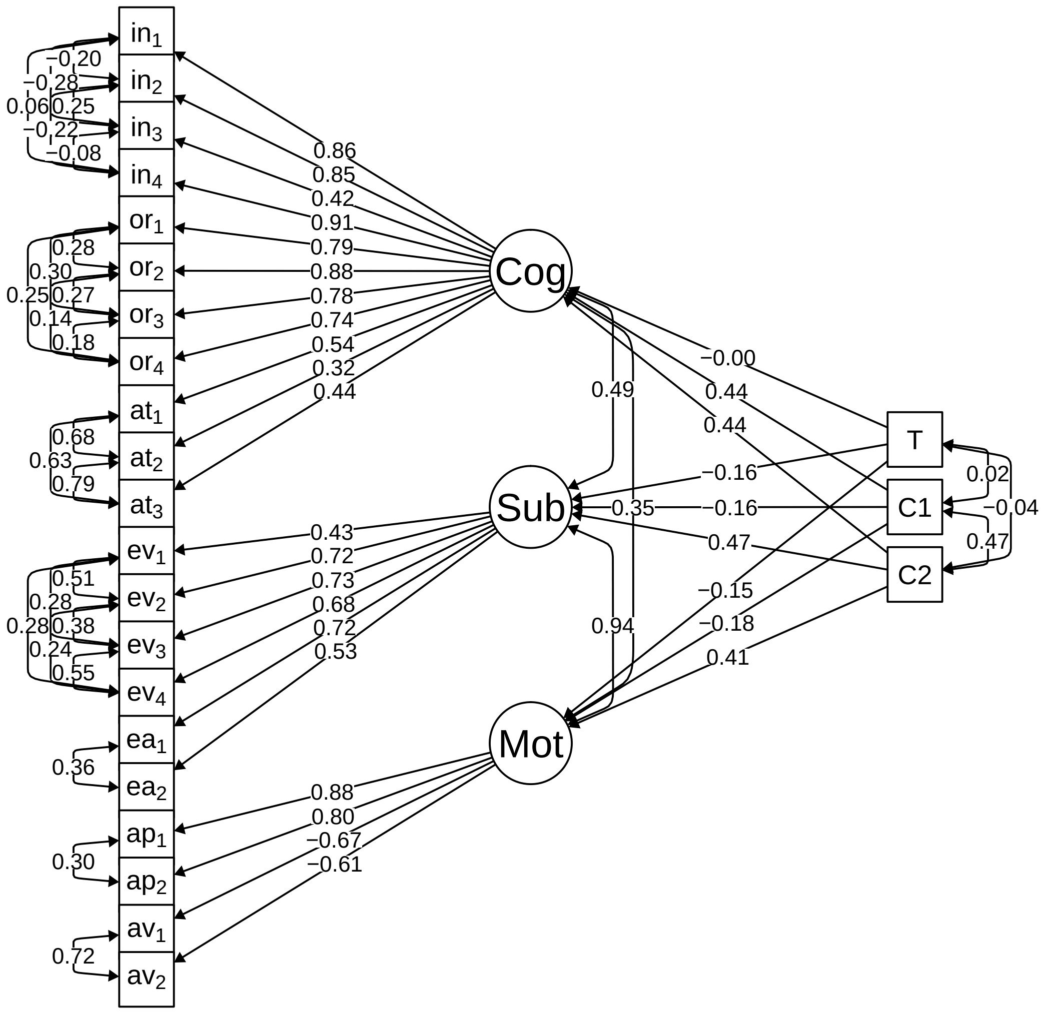

Figure 2

Structural equation model and associated standardized estimates revealing the influence of the subjective (Sub), motivational (Mot) and cognitive (Cog) latent components of emotions on the use of tactile versus non-tactile controllers (C1 and C2) according to the task performed (T). The residuals associated to each item contribution, latent component and predicting variable are not shown for readability.

Table 2

Summary of the hypothesis testing results.

Component	Hypothesis	Result
Cognitive	$H1_a$	Null hypothesis rejected
	$H1_b$	Null hypothesis rejected
Subjective	$H2_a$	Null hypothesis not rejected
	$H2_b$	Null hypothesis rejected
Motivational	$H3_a$	Null hypothesis not rejected
	$H3_b$	Null hypothesis rejected

Finally, the task has a significant influence on the subjective and on the motivational component of emotions (Sub: $b = -0.16, CI[-0.3, -0.02], z = -2.2, p = .030$; Mot: $b = -0.15, CI[-0.28, -0.01], z = -2.08, p = .040$). However the results did not show any significant effect of the task on the cognitive component (Cog: $b = 0, CI[-0.1, 0.09], z = -0.04, p = .970$).

Discussion

Anticipating the user reaction to new technologies is of obvious importance for all industries. This is particularly true with innovative interactive devices that impact everyday use. In this paper, we investigate the self-reported user experience from the use of non-tactile HCI controllers that allow users to use computer applications with a novel gestural interaction. Because users have no existing cognitive scheme to compare to, strong emotions should be triggered when using non-tactile controllers. Indeed, emotion components appear to be a relevant clue to evaluate the user experience resulting from these interactions. Therefore, we identified three pertinent components of emotions to measure: the cognitive component, the motivational component and the subjective component. Then, we hypothesized that the use of non-tactile controllers would trigger more positive and more intense emotions than the use of a common interaction.

Overall, the results validate our hypothesis of significant differences between the emotion components triggered by the different controllers. Users are self-reporting more positive and intense subjective feelings, cognitive appraisal and action readiness with a non-tactile 3D controller compared with a conventional controller. Users are also self-reporting more cognitive appraisal but negative action readiness with a non-tactile 2D controller compared with a conventional controller. Because the interaction with the non-tactile 2D controller was not satisfying enough, users reported avoidance action readiness. These results can be explained by the lack of additional value brought by the non-tactile 2D controller. Indeed, replacing the use of the tactile 2D controller, which is now well integrated in users' practices, with a non-tactile equivalent, requires observable advantages to motivate the users to change practices. Here, the non-tactile 2D controller does not bring enough advantages in term of performance or comfort to justify a change in users' experience especially in the cases of the proposed tasks. However, for specific professional applications which mean users cannot touch the surface (e.g., for sanitary reasons in factories or hospitals) the use of a non-tactile 2D controller would be more justified and trigger a more positive user experience. On the contrary, the experience with the non-tactile 3D controller was rich and enjoyable, which led to a more positive experience assessed by the cognitive, motivational and subjective components of users' emotions. The user experience is more complex than with the 2D controllers as the interaction on another spatial dimension brings new possibilities.

Implications for users' emotional experience

While studying emotions triggered by non-tactile controllers, we have sought to highlight the influence of technology's innovativeness on users' feelings through different components of emotion. Our results are congruent with our hypothesis that emotional user experience will be more intense with the use of a new device and this intensity has been captured by the cognitive, motivational and subjective component of emotions. The first explanation for this result comes from the exploration of new possibilities for users to control a known space. These possibilities are closer to "natural" interactions with computers, particularly the non-tactile 3D controller. Indeed, as in non-tactile interactions, users have a direct feedback between their movements and the results on the application which facilitate the tasks. While the valence and arousal dimensions are relevant to infer users' emotions, a future perspective would be to include the measure of the dominance dimension. The dominance dimension is relevant when evaluating the degree to which a user feels a sense of control over the situation (Broekens, 2012).

A second explanation may be advanced depending on the characteristics of the application tasks used. User tasks have a significant effect on experience even with the same technologies. Accordingly, the results show a distinction on the measured components depending on the applications used. The cognitive component highlights that for both applications, participants perceived the non-tactile controllers as being more innovative and original. This result is a prerequisite to our hypothesis knowing that according to Scherer (2001), appraising the relevance of a stimulus is essential to understanding the triggered emotions.

Then, the measure of the subjective as well as the cognitive and the motivational component of emotions reveals that non-tactile controllers trigger more intense emotions. Non-tactile controllers are richer for users than computer mouse ones thanks to the interaction in a 3D dimensional space. The dynamic and natural aspect of the application control suggests that users are more involved in the tasks and therefore have more intense experiences.

Limitations

The study has several methodological limitations, the first being the sampling approach. In order to improve these initial results, it would be necessary to increase the distribution on participants' gender and age. The second limitation calls into question the generalization of the results. Potential differences between the tasks show that the user experience is highly dependent on context. Many situations and tasks must be experimentally manipulated in order to reach a meaningful conclusion on user emotion triggered by non-tactile controllers. Future studies could use only one of the two tasks listed above and propose two alternative versions, different enough to generate an emotional distinction.

Users' emotions are usually used to measure self-reported categories (Ekman, 1992) or dimensions (Russell & Pratt, 1980). However, because of cognitive bias it is possible that the self-reporting of subjective feelings does not correspond to the emotions actually felt (Ross & Dumouchel, 2004). Therefore, complementary measures of users' emotions can be used by also investigating the cognitive and motivational components of emotions.

Taking into account the influence of the instrumental and non-instrumental qualities of the products implies that these have an impact on the emotional state of the user. Understanding this impact requires an understanding of how an individual assesses these qualities. Therefore, it would be interesting to see how the relevance of a product can be summarized by the evaluation of the non-instrumental qualities of the product, such as the evaluation of its aesthetics, for example, but also, and especially by, the evaluation of its instrumental qualities, such as the perceived ease of use of the product or its perceived usefulness.

Finally, the motivational component can be expressed not only by preparation for the approach or by preparation for avoidance as we have shown, but also by other preparations such as preparing an individual to reject something or someone, to be interrupted by something or someone, or to be exuberant (Frijda, 1987). Therefore, analysis of the motivational component is particularly important when considering the emotions generated by innovative products, as it will be an indicator, potentially a predictor, of the future use of the product.

Theoretical implications and managerial implications

From a theoretical point of view, our study highlights the complexity of emotion through its various components. But even more so, this study provides reflexive feedback on these components and especially when they are applied to the evaluation of the emotion generated HCI.

Overall, the results reveal that innovative products can positively influence the components of emotion, but only in the case where innovation brings real gain in carrying out the task of the user. This distinction underlines the limit of the possibility of generalizing them to all innovative products. Indeed, it would seem that the impact of innovation depends on the type of product. Depending on the evaluation of the intrinsic approval criterion, i.e. the evaluation of the positive or negative character of the product for the individual, the influence of the innovative character on the emotions will be different, even reverse. Similarly, depending on the type of gain brought by the innovation, it may have different influences on the emotions. This criterion of subjective gain can be compared to that of relative advantage (Tornatzky & Klein, 1982). This may explain why the advances in technological innovation are more highlighted than marketing innovation (in the sense of Garcia & Calantone, 2002). While technological innovation aims to help the user complete a task, marketing innovation is sometimes reduced to an aesthetic change that does not affect the completion of the task.

These results also reveal the importance of using a quantitative model when investigating the emotional user experience. Qualitative approaches, such as the Kensei Engineering approach (e.g., Guo et al., 2014; Ishihara et al., 2008), have been used within the product development cycle. Despite being useful to collect users' feedback, they are usually time consuming and are not allowing precise comparisons with similar products. On the contrary, the Component Process Model, which has demonstrated its efficiency (e.g., Scherer, 2019; Scherer & Moors, 2019), can be used to accurately monitor the emotional user experience. Indeed, its quantitative approach permits one to compare evaluations between different phases of the product development cycle and between similar products. In addition, it also allows a fast and low coast evaluation.

This work sheds light on the value of measuring users' emotions when developing an innovative product or service. Professionals will therefore have every interest in taking these measures into account when testing products with their target population to anticipate the likelihood of acceptance. Because emotions are ephemeral phenomena that are difficult to predict (Hassenzahl, 2004), investigating users' emotions appears to be a strategic step in the product development cycle to create a product to elicit desired emotions in order to maximize user acceptance (Meiselman, 2015). Indeed, emotions associated with the use of products or services are important to the customer, and thus to the producer. As a result, producers need to adapt their product or service development cycles to investigate and predict the trigger emotions in a target customer segment (Khalid & Helander, 2006; McDonagh et al., 2009). This, in turn, needs to be performed by the process management practice to avoid and minimize negative emotions, thereby encouraging positive emotions (Desmet, 2003). The goal is to tailor their product development cycles to understand the emotions associated with the product or service, and thus tailor the marketing strategies and offerings to different segments. It will, thus, be crucial for them to come up with products and services that are well aligned with customers' emotions. For instance, to take into account user's emotion in an iterative product development cycle, a structured emotional feedback including all the components should be collected after the development of each prototype, in order to validate the product's features. A comparison with the emotional user experience of competitor products should be done if possible as well as a temporal comparison with the emotional user experience of previous iterations of the prototype. Following this, if the results reveal negative feedback on one or more components, a more qualitative approach could be implemented to understand how to improve this emotional user experience.

Conclusion

Given the sizeable economic investment of technological development, anticipating success has become essential for companies. Therefore, a descriptive framework centred on user experience highlights individuals' emotions as a criterion to predict the future use of products. Our study highlights the interest of the Component Process Model in the analysis of the emotions of users of innovative interaction. Thanks to the application of this model, we were able to show a variation not only of the subjective feelings of the users but also of their cognitive appraisals and their motivational changes. Thus, by experimenting with the component process model of emotions, we have been able to highlight emotion through its multiple components. This multi-component evaluation is rarely applied in user experience studies but it is a reliable framework from the emotion literature that should be generalized in technologies' development cycles.

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We use R [Version 4.0.3; R Core Team (2019)] and the R-packages *lavaan* [Version 0.6.8; Rosseel (2012)], *papaja* [Version 0.1.0.9997; Aust and Barth (2018)], and *tidyverse* [Version 1.3.0; Wickham et al. (2019)] for our analyses and thank their authors for their distribution.

Data availability

All the code written in R and the data are freely available on the following repository: https://github.com/damien-dupre/emotion_innovative_interaction.

Supplementary informations

Supplementary Table 1: List of scales and items used in this study.

Supplementary Table 2: Structural equation model's estimates for latent variables (=~), regressions (~) and residual covariances (~~) included in the model. Missing values represent manifest references of latent variables and non estimated covariances (.pdf file).

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