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I Really did That: Sense of Agency with Touchpad, Keyboard, and On-skin Interaction

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ABSTRACT

Input on the skin is emerging as an interaction style. At CHI 2012, Coyle and colleagues identified an increase in the sense of agency (SoA) as one benefit of skin input. However, their study only compared skin input to button presses and has not, to our knowledge, been replicated. Therefore, we had 24 participants compare skin input to both button presses and touchpad input, measuring SoA using the Libet Clock paradigm. We replicate previous findings regarding increased SoA in skin versus button input and also find that SoA for skin is significantly increased compared to touchpad input. Interview data addressing subjective experience further support these findings. We discuss agency and the experiences associated with skin input, as well as differences to input with non-skin devices.

Author Keywords

Skin input; sense of agency; user experience

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION

The skin is emerging as a touch interface. Skin provides a large surface for input that is always with us and that enables rich types of interaction. Since 2010, several prototypes and user studies have explored input on the skin [8, 13, 21, 25].

Although touch performance on the skin has so far been less accurate than on external surfaces [11], several studies suggest that users prefer input on the skin [7, 22, 23]. One reason for this preference could be a better user experience. Besides single evaluations of specific interfaces [7, 22], it is unclear how touch input on the skin is experienced in general.

One possible mechanism behind the user-experience advantage of skin input, is its association with a higher sense of agency. Sense of agency is well-established term from neuroscience that refers to a user's implicit sense of control, that

their actions are responsible for an outcome [9, 10, 20]. In a 2012 study, Coyle and colleagues showed that users' sense of agency is higher in touching the skin than in pressing a button [4]. This suggests that users may implicitly sense higher control in interacting on the skin than in interacting with external devices.

However, these findings raise several questions. First, do Coyle et al.'s findings reflect an increased sense of agency for skin input over button input, or rather represent an implicit preference for tap input over press input. Were the findings inherent to some aspect of the button used, or do they generalise to cover other devices? Second, it is not clear from the paper by Coyle and colleagues whether the sense of agency is reflected in participants' subjective experience. Earlier work has suggested that sense-of-agency is not necessarily associated with conscious experience reports [6]. Third and finally, we are unaware of replications of the original findings. These findings are increasingly cited as a motivation for research on skin input [2, 12], so investigating whether they hold up seems prudent.

This paper seeks to address the questions raised by Coyle et al. We first replicate and extend the original study, adding a touchpad input condition. This allows us to separate the effects of using the skin from the input modality, and thus address whether an increased sense of agency is a result of skin input or touch input in general. We also collect interview data to identify whether the participants subjectively experience a greater sense of control with any of the input modalities. By addressing the questions raised by Coyle et al., we seek to contribute to the generalisable understanding of what makes skin input good.

RELATED WORK

The sense of agency refers to a person's feeling of control over their actions and the consequences of those actions. Moore [20] explains:

"When we make voluntary actions we tend not to feel as though they simply happen to us, instead we feel as though we are in charge. The sense of agency refers to this feeling of being in the driving seat when it comes to our actions."

This sense or feeling of agency is distinct from higher-level, explicit judgements of agency that involve conscious decisions [24]. Instead it involves lower-level sensorimotor processes. It gives us an innate sense of control and ownership of our actions and allows us to instinctively say, "I did that".

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The sense of agency has been the subject of a large body of research within the cognitive-neuroscience community (see Moore [20] for a review). Researchers in this field have developed techniques through which the sense of agency can be empirically investigated.

More recently the sense of agency has become a focus for the HCI community [3, 17]. This interest reflects the importance of a person’s experience of control when interacting with technology. It also reflects the degree to which key interaction features such as latency, accuracy, and input modality may impact on the sense of agency. As noted by Coyle et al. [4] the sense of agency is a surprisingly malleable experience. From a HCI perspective, this offers both opportunities and pitfalls, and recent papers have begun to investigate the conditions under which interactions with technology either improve or reduce users’ sense of agency.

As noted above, Coyle et al. [4] suggested that skin-based interaction can increase the sense of agency. They also found that simple intelligent interfaces, which interpret and act on users’ intentions, can either increase or decrease the sense of agency, depending on the degree to which the interface offers assistance. Cornelio Martinez et al. [2] found that touchless, mid-air haptic interfaces can provide a sense of agency similar to that supported by physical interfaces. Conversely Limerick et al. [18] found that speech interfaces reduce the sense of agency. Thus, sense of agency is widely recognized as important also outside of skin input.

Libet Clock Method

The Libet Clock method used by Coyle et al. [4] was developed by Haggard [9], who built it on the work of Libet et al. [16]. The method is used for empirically measuring the sense of agency from changes in perceived time. It builds on the phenomena that the perceived time interval between intentional actions and their outcomes is shorter than the actual time interval (Figure 1). For example, when a person presses a button which causes a beep after a short time interval, it is likely that the action is perceived to have happened later and the beep earlier than they actually did. The first of these phenomena is called *action binding*, and the latter *outcome binding*. The sum of these factors describes the main dependent variable, called *intentional binding*, which correlates with a sense of personal agency.

EXPERIMENT

We replicate the Libet Clock experiment of Coyle and colleagues with extensions of (a) adding a touchpad as a third input device, and (b) eliciting subjective feedback from participants using interviews.

The motivation behind (a) was to pursue further insights into whether the difference Coyle et al. found in intentional binding relate to using a body versus an external device for input, or to the input method, that is, taps versus presses. We hypothesised that the smaller intentional binding with button presses is caused by the intrinsic difference in the input modalities: Button press involves three states (released, touched, press) and tap on the skin two (released, touched). Furthermore, the selection time with a button press can be

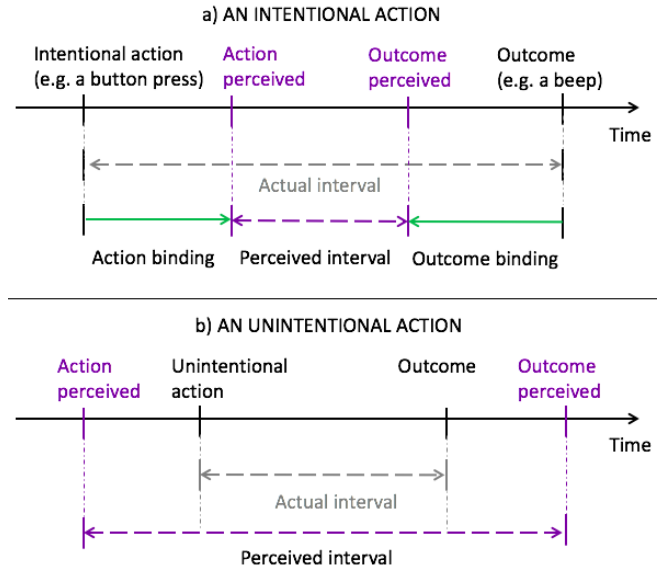


Figure 1. Time perception in an intentional action (a), and an unintentional action (b). For intentional actions, the perceived interval between action and outcome is shorter than the actual interval, while for unintentional actions the perceived interval is longer than the actual.


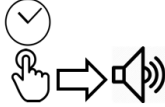


Action measurements	
Baseline error 	The participant is asked to attend to the Libet clock and then press the button whenever they want to. In this case the button press does not cause a beep. The person reports the time on the clock (perceived time) when they pressed the button. The actual time of the button press is also recorded. <i>Baseline error = actual time - perceived time</i>
Active error 	The participant attends to the clock face and presses the button whenever they want to. In this case the button press causes a beep. The person is asked to report the time on the clock (perceived time) when they pressed the button. The actual time of the button press is also recorded. <i>Active error = actual time - perceived time</i>
Outcome measurements	
Baseline error 	The participant attends to the clock face. On this occasion the person takes no action and the computer randomly generates a beep. The participant reports the time on the clock (perceived time) when they heard the beep. The actual time of the beep is also recorded. <i>Baseline error = actual time - perceived time</i>
Active error 	The participant attends to the clock face and presses the button whenever they want to. In this case the button press causes a beep. The participant reports the time on the clock (perceived time) when they heard the beep. The actual time of the beep is also recorded. <i>Active error = actual time - perceived time</i>
Each measure outlined above is repeated multiple times and the mean value for each is then used to calculate Intentional Binding.	
Intentional Binding calculations	
Action binding = Action error [Active] – Action error [Baseline]	
Outcome binding = Outcome error [Baseline] – Outcome error [Active]	
Total binding = Action binding + Outcome binding	

Figure 2. The measurements and calculations used to assess Intentional Binding for an action/outcome condition, using the Libet Clock method. A fixed action/outcome interval of 250 ms is used for all active trials.

ambiguous (i.e., whether the selection happens during a button press, at the bottom of it, or when releasing). Therefore, we added a touchpad condition, which allows us to compare

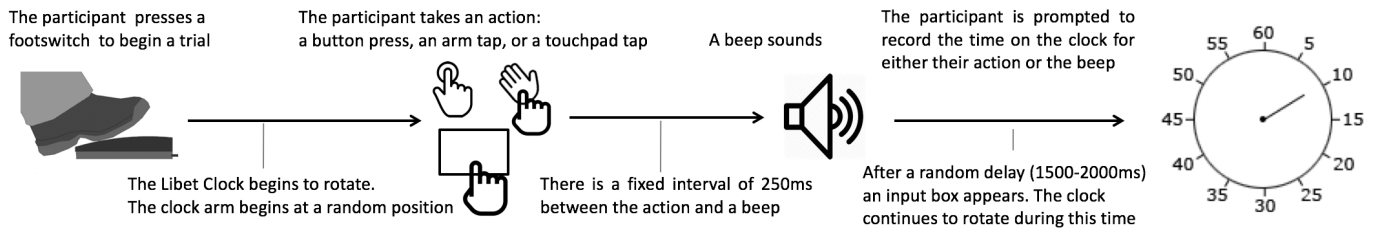


Figure 3. The protocol for the active conditions in the experiment. Baseline conditions omit either the action or the beep. The Libet Clock on the right as shown on a display in the experiment.

a two-state input method similar to tapping on the skin, but on an external device.

The motivation behind (b) was to gain insights on how the use of the three interfaces are subjectively experienced. This allows speculation about whether differences in intentional binding transfer into differences in the experience of interaction.

We emphasize the replication aspect of the present experiment because replications are rare in HCI. Hornbæk et al. [15] found that replications represent only 3% of a sample of more than 800 CHI papers. Others have similarly argued for a need to do more replications, for instance, in the RepliCHI initiative [26]. In this case, a replication is necessary, as the methodology requires a within-participants design, and therefore simply comparing new results from the touchpad condition to the results of Coyle et al. would not have been a valid approach. This replication is also overdue because the findings of Coyle et al. [4] are often cited as a benefit of skin-based interaction (e.g., [2, 12]). On the one hand, we do a strict replication [14] including conditions similar to those used by Coyle et al. On the other hand, we add a condition (point a above), obtain complementary measures (point b above), and run an independent study with different participants, experimenter, and hardware.

Task

The Libet Clock (Figure 3) consists of a clock face with an arm that rotates clockwise through a full cycle once every 2560ms. The participant sits in front of the screen looking at the clock, and is asked to report where the rotating arm on the clock was pointing when an action (input) was performed, or when an outcome (beep) was observed. This task is similar to that used by Coyle et al.

Design

The experiment followed a within-subjects design with the three input interfaces (Button, Skin, and Touchpad). For each interface four measurements are collected: Action Baseline, Action Active, Outcome Baseline, and Outcome Active. (Figure 2) illustrates these four measurements and the calculations for the intentional binding effect. The conditions for measurements are described below in the procedure.

The order of the interfaces and the order of the measurements with each interface were balanced using Latin Squares. The input interfaces were used one at a time to collect all the measurements. Whereas Coyle and colleagues collected 40 repetitions for each measurement, we used 30 repetitions

to maintain a similar experiment duration and to prevent fatigue and loss of attention despite adding the touchpad conditions. Compared to Coyle et al., we added participants to counter effects of a smaller number of repetitions, as well as to cover balancing of conditions including the additional touchpad condition. The experiment duration was approximately 80 minutes.

Apparatus

The experimental setup is shown in Figure 4. The three interface conditions were set up as follows.

BUTTON: Similar to Coyle et al., we used an Enter -key of a USB -connected numpad for the Button condition.

SKIN: For the Skin condition we used a piezo-electric contact microphone similar to that used in Coyle et al. The piezo sensor with a diameter of 2.7mm was wrapped on the participant’s forearm with a medical bandage. In our experiment the piezo was located on the opposite (posterior) side of the arm compared to Coyle’s study. We decided to use the posterior side because that allowed the participants to maintain a natural and comfortable posture, and us to place each input interface to the same location on the table in front of the participant. The piezo sensor was connected to the computer running the experimental software via a high-fidelity sound-card (Focusrite Scarlett 6i6 2nd Gen).

TOUCHPAD: The MacBook’s touchpad was used for the Touchpad conditions. The tap could be performed anywhere

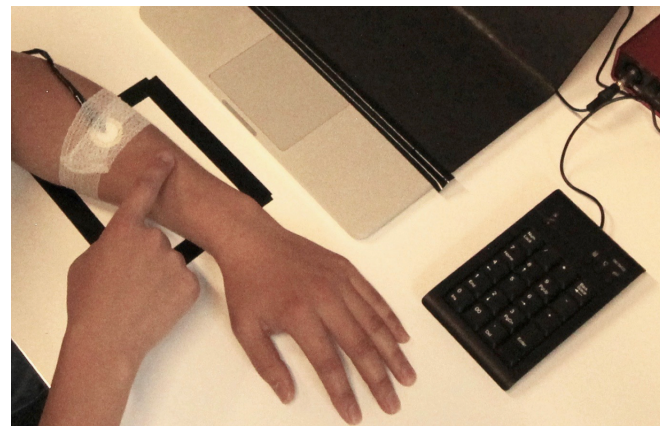


Figure 4. Setup for the three input conditions: Skin, Touchpad, and Button. The input interface was always brought in front of the subject on a designated area (the black rectangle on marked on the table). A separate screen displayed the interface and the Libet Clock.

on the touchpad's active area. The keyboard and the screen of the MacBook were not used during the study and were covered with black cardboard to prevent participant distraction. No audio feedback was used with the touchpad, because the beep sound in this Libet clock experiment is already used for measuring perception of outcome.

A designated area on the table, in front of the participant, was used as the input area for each interface condition (Figure 4). The touchpad and the numpad were stowed away behind the desktop display during other conditions, and the left arm was kept on the side of the table during Touchpad and Button conditions.

Coyle provided the experimental software used in their original Libet Clock study. We used the software for displaying the Libet Clock, running the trials, and for logging the actual times and the reported perceived times. In our experiment the clock size was the same 100 pixels in diameter, and it was displayed on a screen with 1920 x 1080 resolution. We used a MacBook Pro (2013) for running the software and collecting the data. The original software could process sensor signals and recognise taps on the skin, and register actions from button presses. The software was extended to support the Touchpad condition.

Procedure

Before starting the Libet Clock trials, the experimenter ensured that all the input interfaces worked reliably. The signal processing features for detecting taps on the skin were adjusted (increasing sensitivity from the default settings) until 10 subsequent taps could be detected.

The participants were first introduced to the tasks of recording the perceived action and outcome times from the Libet Clock. The participants then had a practice round for each of the four measurement types with each interface. The touchpad was used by tapping (i.e., lifting the finger instead of holding it on the surface and clicking), and the skin was instructed to be used in the same way.

Before beginning the blocks of 30 trials for each interface and each measure, the participants viewed on-screen instructions telling them to record either (a) the perceived action or (b) the perceived outcome time. After reading the instructions, the experimenter revealed the clock face on the screen.

The procedure for the trials is depicted in Figure 3. To start a trial, the participant pressed a foot switch. This caused the clock arm to appear at a random position and start to rotate. In the three trials requiring an action, participants were instructed to wait the clock arm to rotate through at least one full round before performing the action. The random starting point and waiting for the arm to rotate before performing an action helped to discourage planning of action times.

At a fixed 250ms interval after the action, a buzzer sound was played as an outcome. In the outcome baseline condition where no action was performed, the sound was played at a random time between 5000 and 7500ms after the foot switch was pressed to start the trial. After the action or the outcome, the clock arm continued to rotate for a random

time (between 1500-2500ms) and then disappeared. When the clock arm disappeared, the participant told the experimenter the perceived time of action or outcome, depending on the current condition. The experimenter typed the time on an input dialogue on the screen. The purpose of telling the perceived times to the experimenter instead of simply typing those themselves was to encourage the participants to pay attention to the task. This way, the participant was also able to double check that there are no errors in the reported times.

After the all Libet Clock trials were finished, the participants were interviewed. The interview was semi-structured, always starting with a question on the experienced differences in using the three interfaces, and if not already covered in the first answer, followed up by questions on the experienced speed, comfort, and control of the interfaces.

Participants

Data were collected from 24 right-handed participants (10 females, with an average age of 30.95 years). All of them used a computer keyboard and a laptop touchpad daily.

In two cases our system for capturing touches on the skin was not working effectively. However, this behavior was detected already in the beginning of the experiment, and the experiment was discontinued. The next participants were allocated to replace the discontinued ones, resulting to a complete data set of 24 participants.

Three participants, however, misinterpreted experimental instructions in one of the conditions. By examining the action and outcome binding values, we found that two participants had over 200ms values in action binding, and one participant in outcome binding with one of the input interfaces. Because the outcome was played always at a 250ms interval after the actions, these high values imply that the participants had incorrectly reported either outcome values (beep time) when the instructions were to report action values (input), or the opposite. Therefore, all data from these three participants were excluded, leaving 21 participants for the analysis.

RESULTS

In this section we report the results of the Libet Clock experiment, compare those results to the original study of Coyle and colleagues, and describe the interview data.

Intentional Binding

Figure 5 shows the results from the Libet Clock experiment. A one-way repeated measures ANOVA shows a significant difference between the intentional binding values with the three interfaces, $F(2,20) = 8.19, p = .001$, showing a medium effect size of eta squared $\eta^2 = 0.09$. A post-hoc analysis with a Bonferroni corrected paired sample t-test shows this difference is significant between two pairs: Skin and Button ($p = .005$), and Skin and Touchpad ($p < .001$), with respective effect sizes of Cohen's $d = 0.55$ and $d = 0.67$. No significant difference was found between the mean total binding values with Button and Touchpad.

A Bonferroni corrected paired sample t-test further shows significantly higher outcome binding with Skin input compared to Button ($p = .007$) and to Touchpad ($p < .001$).

	Action binding	Outcome binding	Total binding
Button	17.68ms (44.75ms)	36.60ms (56.01ms)	54.28ms (67.56ms)
Skin	25.02ms (42.08ms)	70.52ms (57.97ms)	95.53ms (81.95ms)
Touchpad	21.68ms (49.03ms)	19.64ms (60.16ms)	41.32ms (80.61ms)

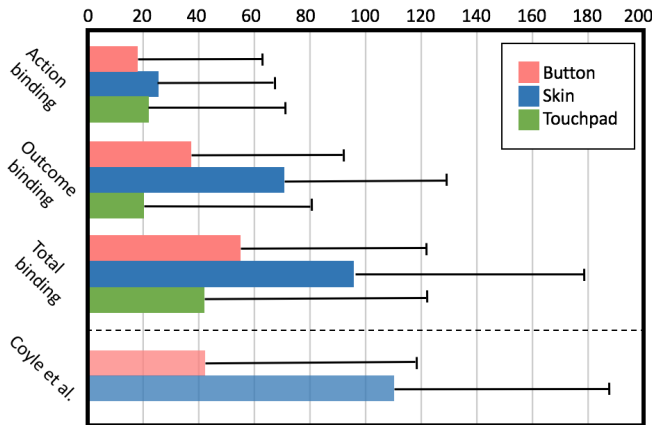


Figure 5. The upper values and the bars denote the mean action, outcome and total binding times in ms for each input condition in the present experiment, as well as the total binding times from Coyle et al. Higher binding values indicate a greater sense of agency. Standard deviations in brackets and in error bars.

These results replicated the significant difference Coyle and colleagues found between the intentional bindings with the Skin and the Button. Moreover, the average values and the difference are consistent: Input on the skin (mean total binding of 95.53ms) in this experiment increased intentional binding compared to Button (54.28ms) and Touchpad (41.32ms), while Coyle et al. [4] reported the total binding of 109.47ms for Skin and 42.92ms for Button. Their effect size was $d = 0.91$. The total binding is further consistent with earlier binding experiments using button input for actions [10, 19].

Our findings on outcome binding values (70.52ms for Skin and 36.60 for Button) are also consistent with those of Coyle and colleagues (79.82ms for Skin and 36.11 for Button). In contrast, the action binding values for Button in our study were in average higher than in Coyle's, thus also leaving the difference to Skin smaller in action binding.

Subjective Experiences

We used the interview data to collect the adjectives the participants used to describe experiences with each interface. Overall, the participants described the experience using the Button with the largest number of positive adjectives (48 instances across the 21 participants), followed by the Skin (18 instances). When asked which interface the participants found the fastest, 10 responded the Button, and four the Skin and the Touchpad, while the rest of the participants did not clearly name an interface for fastest experience. Button was also found to offer the most control over the task (Button: 11 participants, Skin: three participants, Touchpad: four par-

ticipants, the rest did not name any), and the most comfort (Button: 10 participants, Skin: four, Touchpad: four, the rest did not name any).

In addition, the participants described the Skin interface as *responsive, on point, easy, nice, natural, efficient, great, and relaxed*. Button was similarly described as *easy and responsive*, and also *familiar, normal, and simple*. The Touchpad was described as *easy and direct*.

Familiarity of using a keypad for input explains some of the preferences for the Button interface. For example, P13 explained that "the button was definitely more comfortable, because I was more used to [it]", and P17 that "The button pressing on the keyboard felt like it was a game, like a rhythm game. I was familiar with that sort of thing."

In contrast, the novelty of the experience of using the skin for input was reported in both positive and neutral comments. For example, P2 "didn't expect [tapping the arm] to be as good as it was.", and "actually found it easier than using especially the [touchpad]". P6 further described the Skin being "A little bit weird, but quite nice as well. Very scientific and modern", similar to P4, commenting "That was very weird. A new experience, and I guess you're not very used to it, so you don't know how to react to that feeling."

Accommodating to the novelty of the Skin interface was experienced during the study. The participants told that "it took me some time to accommodate." (P3), and that it "felt great. It takes some time getting used to, but it's fun". (P4). Although drawbacks relating to the novelty were experienced, some of those were also overcome. P16 described that "I liked tapping my arm. In the beginning I thought it was a bit confusing, but then it was just tapping one's arm. It kinda felt nice. After pressing my arm for a while it felt more natural". P6 further explained that "you need a little more brain to operate your arm. Because I'm used to tapping my keyboard or my Ipad, I can take my thought off it I don't think about it, but when I have to tap my arm I think that I'm touching myself. And that's a new experience."

The Skin and Touchpad input were also experienced similar in some aspects: P1 reported that "there were some similarities between using the touchpad and the skin", and P19 that the experiment task "was a little bit more difficult with the button, and I think it was almost the same with the touchpad than with the arm."

Touchpad, however, was experienced to lack the feedback which the Skin and the Button provided. Participants describe, for instance, that "[The touchpad] was a bit different because you couldn't feel when you touched it, but you could feel that you touched the computer, so there was no counter reaction" (P4), and that "It feels fine, but because there is not a rebound or an effect from after tapping, I prefer the button." (P10).

Moreover, the participants compared the interfaces in terms of feedback. For example, P14 told that the "[Button] gives very concrete feedback. I could feel it be pressed, and the touchpad doesn't give that same feedback", while on the arm

"I feel it". P16 continues explaining that "When I tapped the enter button it goes down, and when I tap my arm then I feel it. But when I tap [the touchpad] I don't feel it; no feedback." P20 told that "I prefer the button because I feel like it's more of a physical thing that you press so you're more sure that you actually pressed a thing. You feel more in contact with the function because you can feel it on your own body. Pressing your own body feels that you are more connected to what's happening on the screen." P20 further highlights the feedback as a benefit of skin input by describing that "I actually thought that I had better feeling of [the clock] when I used my arm as an interface, because that was of course a physical pressure so that might send some signal to the brain".

DISCUSSION

In this paper, we sought to address a number of questions raised by Coyle et al. [4] in their original paper on the sense of agency in skin input. First, we sought to replicate their findings, in order to confirm the increase of agency with on-skin interaction. Second, we wished to address whether the original findings generalise to other devices, or are inherent to differences between tapping on the skin and pushing a button. Finally, we were interested to explore whether an increased implicit sense of agency is also reflected through subjective comments.

In this paper, we have replicated the finding that skin input increases the sense of agency, originally reported by Coyle et al. [4]. Our effect is medium-sized, and falls within the confidence intervals of the effect size of the original study (ours: $d = 0.55$, .95 CI= [0.19, 0.90]; Coyle et al.: $d = 0.91$, .95 CI= [0.37, 1.44]). We obtained the per participant averages of total binding values found in the original study. We used these to calculate the overall estimation of the effect size. For these two studies the combined effect size is $d = 0.710$.

We also conceptually replicate the finding of Coyle et al. by showing that intentional binding is higher with the skin than when interacting with a touchpad ($d = 0.67$, again a medium effect). This is significant because it rules out the explanation that the difference was incidental to the button used. In particular, it invalidates the concern that taps and presses makes a difference to this effect. Thus, our findings support the idea that the difference is due to using the body as an input device.

Future studies should seek further insights into the differences between sense of agency across bodies and devices. For example, skin interaction is popular for mobile input [8, 11, 13, 25]. Therefore, comparisons could provide insights into the effects of dynamic vs. static input location (e.g., on-skin vs. mobile touchscreen), or rigidity of the input surface (e.g., pressure input on skin vs. touchscreen). When considering these further explorations, researchers should note the following challenges. First, intentional binding studies require many repetitions [4], and are thus lengthy and taxing to participants. As such, it is infeasible to compare many conditions simultaneously. Second, the Libet Clock paradigm requires binary selection modalities and was in the study replicated here used with indirect input. As such, other agency measuring techniques, such as Interval Estimation [4], would be

needed to support exploration of modalities such as pressure-input (continuous input) or touchscreen input (direct input).

Beyond replicating the effects seen by Coyle et al. [4], we began tackling the question of whether differences in sense of agency matter to the user experience. In particular, do medium-sized effects impact how participants experience an interaction? Our data show no clear associations between skin input and experiences that one would a priori consider related to sense of agency. On the most basic level, the button was perceived as affording more control. Similarly, the button was also deemed faster and more comfortable than using the skin. The skin and touchpad conditions differed in participants' assessment of feedback in interaction: In particular the experience of feedback might be expected to be related to sense of agency but such correlation was not found between skin and button input in this study. Although some participants described the skin as 'responsive', 'efficient', and 'natural', all terms that may suggest an explicit sense of agency, their use was not pervasive across participants. Thus, our data suggest an agreement with the explanation that the implicit sense of agency does not necessarily correspond to conscious experience (e.g., [6]).

Future work should investigate this question further. A first step could be to empirically compare the devices we investigated again, but also including measures of control, naturalness [1], comfort, and subjective duration [5] —to name a few measures that sense of agency could likely affect. This could be done in a Libet Clock experiment but also in a more naturalistic comparison of conditions similar to the three tested herein. Furthermore, our subjective data suggests the existence of novelty effects. While the implicit Libet Clock paradigm is not impacted by such effects, the counterpart subjective experience may be, and future work should mitigate this when seeking to draw parallels.

The sense of agency has gained a lot of attention in HCI (e.g., [2, 18]). But if agency means little or nothing to the conscious user experience, then perhaps this attention is misplaced.

CONCLUSION

Input on the skin is emerging as an interaction style; earlier work has suggested that this is tied to the sense of agency when interacting on one's own skin. In particular, Coyle et al. [4] provided data showing increased intentional binding for on-skin interaction compared to interaction using a button. We have replicated these findings and shown that the differences in agency can also be found with other devices than buttons (here, a touchpad). We also showed that the subjective experience of interaction is not affected in a straightforward manner by these differences, calling for further work that investigates if sense of agency affects conscious user experience.

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