Presstures: Exploring Pressure-Sensitive Multi-Touch Gestures on Trackpads

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ABSTRACT
In this paper, we present *Presstures*, an extension to current multi-touch operations that enriches common multi-finger gestures with pressure information. By using the initially applied pressure level for implicit mode switching, a gesture can be enhanced with different functionalities to enlarge the interaction space for multi-touch. To evaluate the feasibility of our concept, we conducted an experiment, which indicates good human sensorimotor skills for performing multi-touch gestures with a few number of pressure levels and without any additional feedback. Based on the experimental results, we discuss implications for the design of pressure-sensitive multi-touch gestures, and propose application scenarios that make optimal use of our concept.

Keywords
Pressure; Force; Pressure Gestures; Multi-Touch Gestures

ACM Classification Keywords
H.5.2. [Information interfaces and presentation]: User Interfaces: Input Devices and Strategies, Interaction Styles.

INTRODUCTION
Pressure-sensitive input has been a topic of interest in the HCI community for several years now, with research efforts ranging from explorations of pressure as alternative input metaphor [3,4,10] to the development of pressure-sensitive input devices (e.g., mouse [1], stylus [6], touchscreen [4]). To date, pressure has been used for a variety of applications such as zooming [8], scrolling [7], text entry [5], or widget control [9]. A comprehensive overview of existing work in the field, and foundations of human pressure control abilities can be found in [14]. More recently, with touch interaction becoming increasingly present in our daily lives, pressure has also been introduced as additional input dimension for touch-based applications. Addressing this arising potential, we propose coupling common multi-touch gestures (e.g., pinching) with pressure information into a concept called *Presstures* (*press*ure-sensitive multi-touch ges*tures*). Besides the use of continuous pressure values or shear forces for interactions like zooming [8] or scrolling [7], we believe that discrete pressure levels provide high potential as implicit mode switching technique for multi-touch gestures. Likewise used for single-touch and stylus interaction [2,9,10], there has not yet been any investigation on pressure-based mode-switching with multiple fingers. Therefore, we see our concept as alternative to existing mode-switching approaches (e.g., [13]), which provides particular benefits for learnability and memorability by simply enhancing known gestures with different functionalities.

Previous work has pointed out that feedback is essential for pressure interaction to control a larger amount of pressure levels [6,9]. Depending on the context, researchers conclude that users are capable of controlling around eight to ten pressure levels [1,6,11,14]. In these papers, the researchers mostly evaluated the human's ability to adapt to predefined pressure targets based on additional feedback. In contrast, we were interested if it is possible to make use of the users' individual pressure perception in order to make an adaption to predefined targets obsolete. On the one hand, this limits the number of possible pressure levels to a smaller amount of levels compared to related work, but on the other hand it results in a more fluid interaction and a simpler interface design since users no longer need to adapt to additional visual feedback. Hence, to make participants focus on their pressure perception, the experiments in this paper were deliberately designed to provide neither visual feedback nor further guidance in order to eliminate any effects and explore the limits of pressure interaction without external feedback.

Summarizing, our contribution consists of (I) the investigation of human sensorimotor skills to control a small number of pressure levels (i.e., light-strong, light-medium-strong) for multi-touch gestures without external feedback, (II) the discussion of resulting implications for the design of pressure-sensitive multi-touch, and (III) the suggestion of associated application examples.

CONCEPT
Holding strong pressure over long distances is uncomfortable and also limits speed and accuracy. Therefore, Heo and Lee propose to select a mode based on pressure before the actual single finger drag gesture [2], which we extended to pure multi-touch gestures. In further contrast, we propose to

delimit the initial phase of defining the mode based on distance. Once the contact point exceeds a distance larger than the average size of contact area (~1.5 cm), the pressure evaluation terminates, and the highest pressure value by then is used for defining the mode. This has the advantage of producing no perceptible lag like a dwell timeout [2, 10] and provides a seamless transition between mode switch and gesture. Beyond, similar approaches used different pressure levels to overload a mobile phone keyboard [5] or multiple touch strips [12] with different functionalities. However, the users' ability to control pressure levels with multiple fingers was not tested systematically.

USER STUDY

To study the participants' sensorimotor skills for controlling pressure, we conducted a study to investigate the following questions: (1) Does the perception of pressure levels differ from user to user? (2) How many different pressure levels, applied by multiple fingers, can be controlled without visual feedback? (3) Are users capable of initiating a multi-touch gesture with a specific discrete pressure level?

To answer those questions, we split the study into two experiments. In the first experiment, we studied the participants' sensorimotor skills to control different pressure levels with one or two fingers and without any feedback. In the second experiment, we investigated the feasibility of initiating multi-touch gestures with a specific pressure level.

We recruited 8 unpaid participants aged 20-30 years (*Mdn* = 22) from a local university (6 female; 1 left-handed). Participants were highly experienced in performing touch gestures (5-point Likert*; Mdn = 5, SD = 0.76*) and moderately experienced with multi-touch gestures on trackpads (*Mdn* = 3, *SD* = 1.58).

As sensor we used a *Synaptics ForcePad* (cf. Figure 1, left), a pressure-sensitive trackpad (11×7 cm) that combines capacitive finger tracking with four force sensors at each corner. An interpolation algorithm is used to compute pressure for each of the maximum five touch points. Our findings with an analog scale showed a perfect linear measurement range up to 2000 grams.

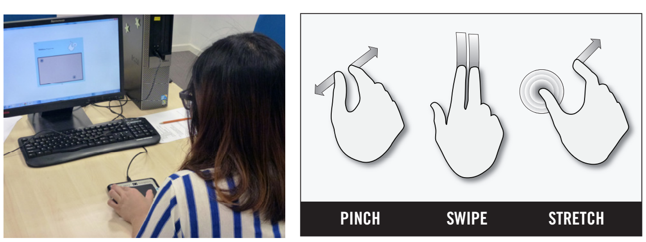

Figure 1: Study apparatus (left) and gesture set (Exp. 2, right).

For both experiments, trials were counterbalanced and the pressure level targets within every condition were randomized to prevent ordering effects. To increase comparability of the results, we specified which fingers had to perform the tasks within all conditions. Furthermore, we included a short training phase to familiarize participants with both the device and the task. Since we expected user-dependent pressure sensations, the study included an initial calibration phase for static touches with one and two fingers, which we used to gain user-dependent thresholds for the calculation of accuracy rates during the study.

Experiment 1: Task & Results

The goal of the first experiment was to explore if participants were able to control different levels of pressure without any feedback, based on their own pressure perception. We used a 2×2×2 within-subjects factorial design, with different amounts of pressure levels (*2-levels, 3-levels*), one or two fingers (*1-finger, 2-fingers* with equal pressure on both fingers) and different hand conditions (dominant *DH*, non-dominant *NDH*) with 160 trials in total (16 per block for *2-levels,* and 24 for *3-levels*). Participants were free to choose the pressure levels as they felt comfortable with.

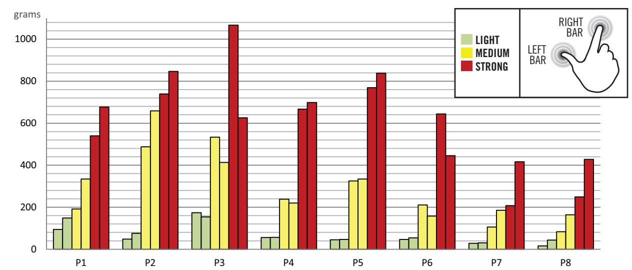

Figure 2: Mean pressure values for both fingers (2 bars of same color) in the light (green), medium (yellow), and strong (red) conditions of experiment 1.

As depicted in Figure 2 (*2-fingers*, *3-levels*) pressure sensations differed significantly from participant to participant, with significant effects for light (t_7 = 4.132, p = .004), medium (t_7 = 5.122, p = .001) and strong pressure (t_7 = 8.438, p < .001). These high differences are a drawback of offering no feedback, because participants had to rely on their individual pressure perception. Moreover, differences between participants were also dependent on other factors (e.g., finger flexion, contact areas, or sensorimotor skills). This indicates that fixed thresholds are not suitable for mode-switching based on discrete pressure levels without visual feedback. Therefore, we extracted user-dependent boundaries for the pressure levels from the calibration data by fitting thresholds between the average pressure values for each pressure level condition. Moreover, we observed that the applied pressure for gestures with movement was around 30% lower than for static fingers. Thus, to classify the pressure level for a gesture with movement correctly, we adapted the thresholds accordingly.

Although the ability to apply same pressure on both fingers differed between participants, the first experiment revealed that participants were able to control pressure levels without any visual feedback. The accuracy (cf. Figure 3) was high for two levels (M = 98.2%, SD = 4.6) and acceptable for three levels (M = 87.1%, SD = 11.2). A repeated measures ANOVA showed a significant main effect for pressure levels ($F_{1,7}$ = 38.073, p < .001). Most errors in the 3-levels condition occurred in the medium pressure condition (59%), followed by the strong pressure (30%), and light pressure condition (11%). This is not surprising, since applying pressure as light or as strong as possible is less challenging than applying some pressure in between, which was confirmed by comments of four participants.

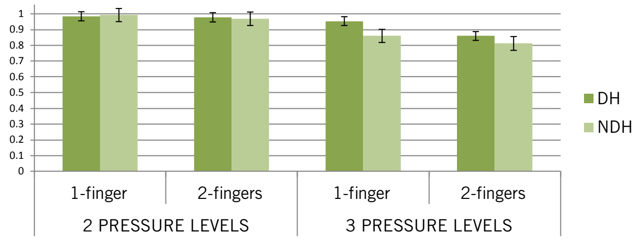

Figure 3: Mean accuracy for controlling two and three pressure levels with one and two fingers in experiment 1 (error bars show 95% confidence intervals).

Experiment 2: Task & Results

For the second experiment, the goal was to explore if participants were able to initiate a multi-touch gesture with a specific pressure level. It was designed as 3×2×3 within-subject factorial design with three types of gestures (*Pinch, Swipe,* and *Stretch;* shown in Figure 1 right), two different amounts of pressure levels (*2-levels, 3-levels*) and three hand conditions (dominant *DH*, non-dominant *NDH*, and index fingers of both hands *BH*) with 360 trials in total (16 per block for *2-levels,* and 24 for *3-levels*). Stretch is defined as Pinch, where one finger is static and applies pressure, while the other finger is swiping (since this gesture might be well-suited as *Pressture*). Participants were instructed to apply the target pressure before movement.

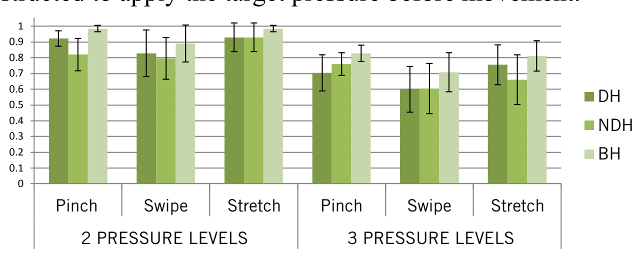

Figure 4: Mean accuracy for initiating a multi-touch gesture with a specific pressure level (Experiment 2).

Analysis (cf. Figure 4) showed that participants were able to initiate multi-touch gestures with constantly good accuracy for two pressure levels (M = 89.6%, SD = 14.66). Nevertheless, they encountered serious problems with controlling three pressure levels (M = 71.5%, SD = 18.2), which is also in line with the participants' comments (P3, P4, P8), stating that it was much harder to perform three-level gestures compared to two-level gestures. We found a significant effect for levels ($F_{1,7} = 87.076$, $p < .001$) as well as for hands ($F_{1,7} = 19.617$, $p = .002$). We assume that the significance for the hand conditions is mainly due to participants not being used to perform gestures with their non-dominant hand. Interestingly, most errors occurred with the Swipe gesture, which was rated as easiest and least demanding. Given that, participants tended to perform it very quickly, thereby establishing the target pressure level only during motion.

DISCUSSION & LIMITATIONS

The results of the study indicate difficulties for users to control more than two pressure levels, especially in combination with multi-touch gestures. In order to explore human sensorimotor skills in controlling certain pressure levels, the experiments were designed to provide no visual feedback or guidance to make participants focus on their sensorimotor perception. However, as this is not an every-day task for most of us, we believe that user performance could greatly be improved with functional feedback provided by a system (i.e., the intended action being executed). Research has shown that pressure interaction in general has a steep learning curve [5], as also confirmed in many real-world examples that build on human capabilities to improve sensorimotor skills with practice (e.g., playing the piano). Beyond that, we believe that *Presstures* can perform even better with decent or indirect feedback in the user interface.

While study results show good results for two pressure levels, we found surprisingly high variations in participants' abilities to control three pressure levels. Although pressure receptors are at high density at finger tips [14], one possible explanation could be limitations of human sensorimotor skills when it comes to the control of intermediate pressure levels without indicators/borders. Moreover, we observed an interesting effect during the study, which showed relative dependencies between trials (e.g., after a strong pressure trial, participants tended towards applying increased pressure in the next trial). In the present study, this finding was not covered by our thresholding approach that fits thresholds between the average pressure values of the calibration phase. Tailoring the algorithm towards non-linear human pressure perception could lead to increased performance (e.g., [11]). Beyond, for two levels it seems feasible that the threshold could be derived from the users' normal interaction force. As the above mentioned factors might have influenced the experimental results, alternative methodologies and hardware could also lead to different results.

Overall, our findings show that pressure-based interaction concepts such as *Presstures*, which is based on users controlling discrete pressure levels without additional feedback, shows only good performance for two pressure levels. For increased numbers of pressure levels, it seems more optimal to provide additional feedback that supports users in adapting to pre-defined pressure targets [6,9]. Nevertheless, we believe that there are definitely applications, which can benefit from pressure-based input that is not reliant upon additional visual feedback (e.g., to keep the interface simple). Moreover, we believe that *Presstures* can be particularly beneficial for expert users, as augmenting different gestures with pressure-sensitivity provides great potential to enlarge interaction space for multi-touch interaction.

APPLICATIONS

The insights gained in the user study inspired us for numerous application scenarios for *Presstures*, which build on users' good abilities to apply two pressure levels:

Hierarchical Selectors can be used for mapping the input scope to different GUI-levels. On operating system level for example, horizontal two-finger swiping with light pressure could scroll the content of an application window, whereas strong pressure could snap the window to a certain screen position (cf. Figure 5). Likewise, pinching with light pressure could be used for content zooming, whereas strong pinching could minimize/maximize a window respectively.

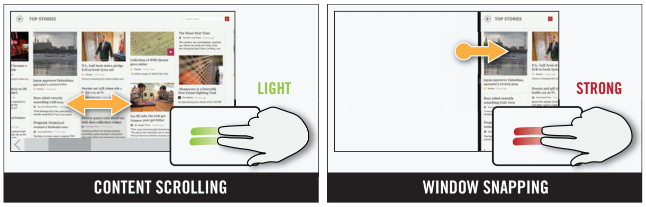

Figure 5: Swiping with light pressure scrolls the content (left), whereas strong pressure snaps the window to the side (right).

Mode Selectors can be used for fluent alternation between different manipulation modes. In a text editor for example, pinching with light pressure could zoom the text, whereas strong pinching could be used to adjust font size. Text selection could be accomplished by performing Stretch gestures that combine strong pressure of the static finger to initiate text selection, and light pressure of the sliding finger to modify the selection area (cf. Figure 6, left).

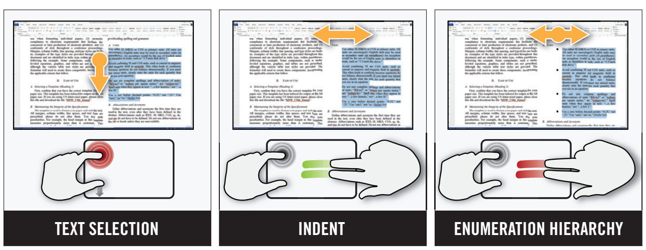

Figure 6: "Stretching" with the non-dominant hand selects text (left). Additional swiping with the dominant hand changes text indent (middle) or enumeration hierarchy (right).

Beyond that, the concept can be easily extended for bimanual interaction scenarios, where different gestures could be performed with both hands simultaneously. Thus, having specified a text selection with the non-dominant hand, the selected text could then be modified through multi-touch gestures with the dominant hand. Thereby, light/strong horizontal swiping could control the text indent or enumeration, and light/strong vertical swiping could modify the font type or style respectively (cf. Figure 6, middle/right).

CONCLUSION & FUTURE WORK

In this paper, we proposed gestures that augment common multi-touch with pressure information. In a user study, we demonstrated the limits of human skills for such pressure-based multi-touch gestures, and its feasibility for implicit mode switching. Based on results showing good performance for two pressure levels, we proposed several application examples. In a subsequent informal user study, participants overall liked the concept, as they perceived multi-touch interactions more effortless and fluent. In our future work, we plan to compare the feasibility of our non-feedback threshold-based approach to existing feedback-based pressure targeting solutions, and explore whether our findings will transfer to other pressure-based input devices.

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