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Study on Behavioral Characteristics of 3D Touch in Smartphone

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Objective: The objective of this study is to identify the difference in the press behavior characteristics of 3D Touch, which is a new touch interaction of smart phones, and the existing 'Tap and Long Press' touch interaction, and to examine behavior changes upon feedbacks.

Background: Since 3D Touch is similar to the existing 'Tap and Long Press' touch interactions in terms of press behavior, which is likely to cause interference, it is necessary to conduct a preliminary study on behavior characteristics of touch interactions.

Method: In utilization of smart phones with the 3D Touch function to measure press behavior characteristics of touch interaction, an experiment was conducted where 30 subjects were given a task to press 30 buttons of touch interactions on the screen. During the experiment, two press behavior characteristics—maximum touch pressure and press duration—were analyzed. To grasp changes in behaviors upon feedbacks, the task was carried out in a condition where there was no feedback and in a condition where there were feedbacks of specific critical values.

Results: While there was no feedback given, subjects tended to press with much strength (318.98gf, 0.60sec) in the case of 3D Touch, and press the Long Press button for a while (157.12gf, 1.10sec) and press the Tap button with little strength only for a short moment (37.92gf, 0.10sec). 3D Touch and Long Press had an area of intersection in time, but when feedbacks of specific critical values were given, there were behavior calibration effects to adjust the press behavior characteristics of 3D Touch and Long Press.

Conclusion: Although interferences are expected between 3D Touch and Long Press due to the similarity of press behaviors, feedbacks induce behavior calibration. Hence, once feedbacks were provided with 3D Touch operated in an appropriate condition of critical pressure, interference between two motions can be minimized.

Application: The findings of this study are expected to be utilized as a basis for the values of optimal critical pressure, at which users can easily distinguish 3D Touch from Long Press which is the existing touch interaction.

Keywords: 3D Touch, Force touch, Embodied cognition, Motor schema, Touch feedback

1. Introduction

Recently, leading smart phone manufacturers have released models with 3D Touch functions. Since 3D Touch makes it possible to sense and classify the extent of strength to press the display, this is a technology that lets users experience a new level of

interaction. In addition to iPhone 6s of Apple, various models of Huawei Mate S, ZTE AXON MINI, and Meizu Pro 6 adopt 3D Touch functions (Figure 1), and according to the HID, a market survey agency, one out of four new smart phones released in 2016 will adopt 3D Touch functions. Besides, major 3rd Party applications actively apply 3D Touch for major 3D Touch UIs such as contents preview and shortcut to menu items. Thus, it is highly probably that 3D Touch will be a new standard for touch interactions of smart phones.

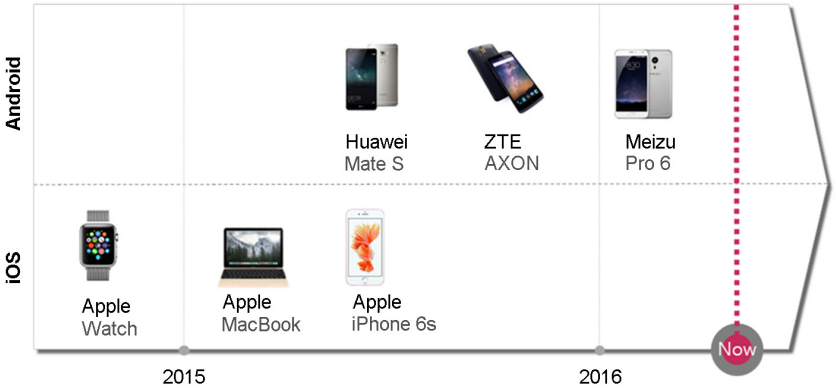


Figure 1. Current status of 3D Touch in mobile devices

3D Touch provides users with new, colorful experiences by adopting the feature of touch pressure that creates a new dimension of Z-AXIS. However, this may cause confusion to users who are familiar with the existing mode: The existing Tap and Long Press are similar to display-pressing motions of 3D Touch (Table 1), and thus using these functions along with 3D Touch can lead to a motion that is different from what a user intended. Particularly, the two modes of 3D Touch—Long Press and Deep Press with strength—are similar to press behaviors, and thus it may be hard for users to distinguish them.

Table 1. Operations for each touch interaction type

Touch type	Description
Tap	Press the surface of touch display and briefly lift the finger
Long press	Press the surface of touch display during certain amount of time
3D Touch	Press the surface of touch display with certain amount of pressure level

As for smart phone operation systems, Long Press is limitedly used only for access to the editing mode in the Home screen of iOS while in Android, it is utilized for various other functions as well such as loading the context menu from the contents list, UI element resizing, relocating, etc. In the perspective of Android smart phone manufacturers who take into account introducing 3D Touch, therefore, designing 3D Touch and Long press in a way that users can easily distinguish one from the other is a more important challenge to be addressed.

2. Literature Review

Many existing researches on 3D Touch suggest the potential of Z-AXIS as a newly added input method that distinguishes Touch

from Press (Buxton, 1990; Rekimoto et al., 2003) although there have been little researches on ways to minimize interference with Tap and Long Press, two of existing touch interactions of smart phones.

For 3D Touch to be firmly established as a standard for touch interactions that can provide users with a new dimension of experiences in terms of practicality, it is necessary to grasp press behavior characteristics of Tap and Long Press being currently used and press behavior characteristics that users expect from 3D Touch, to take them into account for 3D Touch critical pressure designs, and thus to minimize inferences between touch interaction motions.

In a theoretical perspective, examining concepts of 'Embodied Cognition' and 'Motor Schema' is necessary in order to grasp specific press behavior characteristics of 3D Touch and other touch interactions. According to the theory of 'Embodied Cognition', a process of recognizing a certain object is based on a human body's movements for the practical use and contexts of utilization (Lakoff and Johnson, 1999). According to related researches, physically heavier objects are regarded as more important (Jostmann et al., 2009), and important objects are recognized as heavier (Schneider et al., 2011). In this perspective, as a process of cognition interacts with activities of a human body, it is thought that there is a close relation between learned experience or conceptual thinking and press behavior in terms of touch interaction. In addition, Bartlett and Burt (1933) and Schmidt (1975) define a motor schema as a set of comprehensive and general specifications of muscular commands that are related to how to achieve a desired goal and stored in long-term memory. In view of this concept, press motions in relation to experience and conceptual thinking of each touch interaction may show a consistent tendency.

According to existing researches, feedbacks and grip postures are two major factors that can affect press behaviors.

First, preceding studies on the effect of feedbacks indicate that when tactile feedbacks are given for a press behavior, the performance results were different from those when there was no feedback given: When no feedback was given, more strength was applied for pressing than when there was a feedback given (Mizobuchi et al., 2005); and in an assignment to learn the order of strength regulation according to the trajectory, the best learning performance was observed when both visual feedback and tactile feedback were provided (Morris et al., 2007). Such existing studies suggest that the use of feedbacks needs to be taken into account since they can affect press behaviors in touch interaction. Particularly, compared to simple press interactions such as Tap where there is no need for strength or time regulation, 3D Touch and Long Press which may produce different results depending on the pressing strength or time require constant data processing and judgment based on given feedbacks during the pressing motion. Hence, taking into account the effect of feedbacks is essential.

Second, smart phone users touch the screen while gripping the phone. Hence, press behaviors might be varied depending on the grip posture. If a user holds a phone with one hand and manipulates it with another hand, fingering may be relatively free. In contrast, if a user has to grip a phone with one hand and touch the screen with the thumb of that hand, the fingering range of the thumb is limited. As a result, the strength of touch pressure may be significantly varied. According to existing researches, when the screen is touched by the thumb with the phone gripped in one hand, there are certain spots hard to be touched as shown in Figure 2 (Hoober, 2013), and the level of physical inconvenience may be varied accordingly (Parhi et al., 2006). In this perspective, differences among touch areas need to be considered when press behavior characteristics of 3D Touch and Long Press, for which the press strength and time should be regulated, are to be grasped.

3. Purpose of Study

This study aims to clarify press behavior characteristics depending on touch interactions so that users can easily distinguish and use 3D Touch, which is highly probably to become a new standard for smart phone touch interactions, without interferences with existing touch interactions such as Tap and Long Press. In addition, as for 3D Touch and Long Press for which the press strength

(a) Reachable areas for thumb (b) Comfort areas for thumb

Figure 2. (a) Approximate diagram of reachable areas for thumb (Green indicates the area a user can reach easily, red indicates the area a user cannot reach easily), (b) Comfort areas in 9 regions of the device when holding it with one hand (Depth of color indicates more comfort).

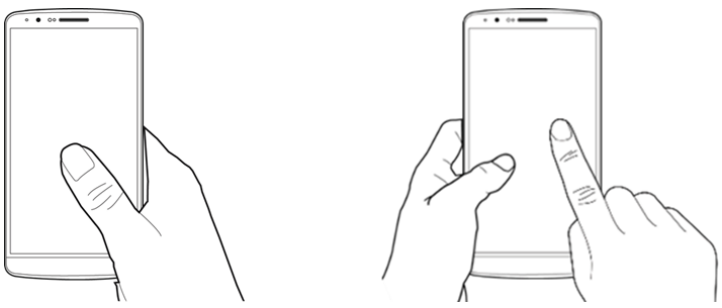
and time may need to be adjusted, differences in press behaviors depending on touch spots and press behavior changes upon feedbacks are also examined.

The findings of this study on press behavior characteristics in relation to touch interactions are expected to be a basis for designing optimal critical values that help users easily distinguish 3D Touch from existing touch interactions.

4. Method

4.1 Research hypothesis

The objective of this study is to grasp differences in press behavior characteristics of 3D Touch and the two existing touch interactions—Tap and Long Press—of smart phones. Since press behaviors can be easily affected by phone grip postures and pressing fingers, this study examines press behaviors in a one-hand grip posture where the user presses the screen with the thumb in a posture where the user holds the phone with one hand and presses the screen with the other hand's thumb, which are two major postures of using smart phones as shown in Figure 3. In addition, the difference in pressing strength depending on the gender is also analyzed.



(a) One hand grip (b) Both hands grip

Figure 3. Two main grip postures for smart phone

As for 3D Touch and Long Press which are subject to effects of feedbacks, differences depending on whether there is a feedback are also examined. As recent models have larger screens, some spots may be hardly approached in a one-hand grip posture depending on the range of fingering. Accordingly, differences in press behaviors depending on touch areas are also analyzed.

Research hypotheses of this study are as follows:
Hypothesis 1: Press behavior characteristics of 3D Touch would be different from those of Tap and Long Press depending on users' posture and gender.
Hypothesis 2: 3D Touch and Long Press may involve changes in press behavior characteristics depending on whether there is a feedback.
Hypothesis 3: In a one-hand grip posture, 3D Touch and Long Press may involve differences in press behaviors depending on touch areas.

4.2 Experimental design

4.2.1 Independent variable

Independent variables for the verification of Hypothesis 1 include touch interaction types (3D Touch, Long press, Tap) and user postures (one-hand posture and both-hand posture), both of which are of the within-subject factor, and gender distinctions of the between-subject factor (male, female). The 3x2x2 mixed factors design is applied. Independent variables for the verification of Hypothesis 2 include touch interaction types (3D Touch, Long press) and whether there is a feedback (with feedbacks, without feedbacks), both of which are of the within-subject factor. The 2x2 within-subject design is applied. Independent variables for the verification of Hypothesis 3 include touch interaction types (3D Touch, Long press) and touch areas (buttons in rows are divided into 5 areas), both of which are of the within-subject factor. The 2x5 within-subject design is applied.

4.2.2 Dependent variable

Dependent variables applied to the experiment include the maximum touch pressure and press duration, as shown in Figure 4, to grasp press behavior characteristics quantitatively: 3D Touch and Long Press motions are based on the touch pressure and time. Maximum touch pressure may be defined as the highest pressure during the period from a user's pressing the display surface (Press) to the moment that the finger is off the surface (Release) (gf, 1gf=0.001kgf). Press duration is defined as the time (sec)

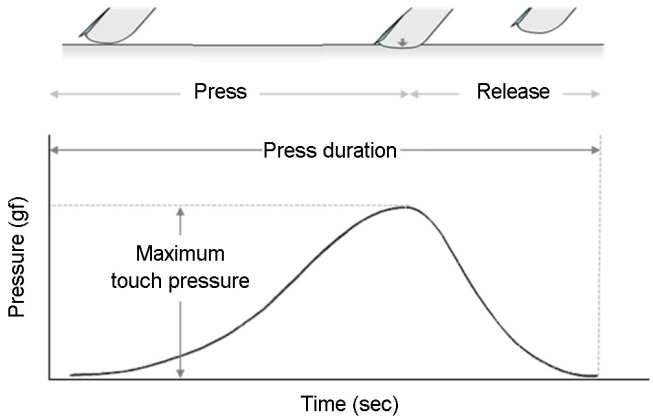
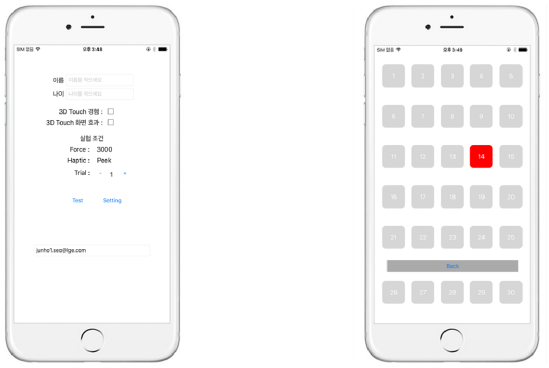


Figure 4. Measurable factors for press behavior

during the period from a user's pressing the display surface (Press) to the moment that the finger is off the surface (Release). In this study, the maximum touch pressure and press duration the press task are measured as touch interaction factors.

4.3 Apparatus and experimental task

For the press behavior measuring device, a software program to measure the touch pressure and time was designed and used in the experiment for the iPhone 6s plus (5.5 inch; 158x78mm) equipped with the 3D Touch hardware. For pressure measurement calibration of the designed experimental apparatus, the gf value was measured by means of a switch feeling tester of DIGHTECH. The value was then compared with the API value presented by the apparatus' software program, converted into the gf value, and then used as the pressure value measurement. The maximum pressure measurable by the apparatus is 340gf. In an existing research (Mizobuchi, 2005), the appropriate touch pressure was set to 300gf in consideration of physical convenience. Accordingly, it is possible to measure the touch pressure within the appropriate range. As shown in Figure 5, the experimental apparatus is designed to have the press area in which 30 touch buttons are arranged. Since a major smart phone manufacturer applies 3D Touch UI functions to the Home icon, the number of buttons is 30, which is the number of Home icons.



(a) Screen for setting (b) Screen for task

Figure 5. Experimental apparatus

The experimental task is to press red ones among 30 buttons on the screen in reference to the given touch interactions. When a red button is pressed during the task, the button disappears, and then another button turns to be red and is presented in random order. Once all the 30 buttons are pressed and disappear, it is viewed that the task is completed. If the task is completed in each given condition, the maximum touch pressure and duration time at each button location are recorded and saved in a log data automatically.

To verify Hypothesis 2, when the specific critical value is reached in the task of 3D Touch and Long Press, the button disappears with a tactile feedback presented. For 3D Touch, the critical pressure is set to 150gf at random, and for Long Press, 0.8sec, which is the default value for Android smart phones of L Company.

4.4 Experimental procedure

Prior to the experiment, subjects were given an instruction about the research purpose and experimental procedures as well as 3D Touch functions so that they could learn and be familiar with how to use 3D Touch functions.

First of all, 3 touch interactions (3D Touch, Long press, Tap) are presented at random depending on the user posture (one hand and both-hand postures) by using the experimental apparatus with no feedback so that subjects carry out the given task. The same task is them carried out on 3D Touch and Long Press this time with feedbacks given. Users can press Tap and Long Press as they would do habitually, and they are asked to press 3D Touch to the degree that no physical load is applied. The experiment takes about 40 minutes.

4.5 Subject

Experimental participants include 30 individuals, 15 men and 15 women respectively, in their 20 to 40s. Basically, participants are familiar with smart phones so that there would be no problem with carrying out touch interactions by using a smart phone. They are right-handed with no problem in applying strength to fingers for pressing behaviors.

5. Results

5.1 Press behavior characteristics in each touch interaction depending on the user posture and gender

5.1.1 Maximum touch pressure

A variance analysis was conducted to examine the effect of independent variables. The result shows that there was significant difference depending on the user posture and touch interaction type on the significance level of 1% (Table 2), and that there was interaction depending on the user posture and touch interaction type on the significance level of 10% (Table 2).

Table 2. ANOVA summary table of maximum touch pressure

Source	DF	SS	MS	F	Pr>F
Posture	1	27774	27774	13.52	0.000***
Gender	1	32	32	0.02	0.901
Touch type	2	2388087	1194043	581.16	0.000***
Posture x Gender	1	1182	1182	0.58	0.449
Posture x Touch type	2	12474	6237	3.04	0.051*
Gender x Touch type	2	198	99	0.05	0.953
Posture x Gender x Touch type	2	8420	4210	2.05	0.132
Errors	168	345168	2055		
Total	179	2783334			

*p<0.1, **p<0.05, ***p<0.01

As for postures that involved significant difference, when the thumb was used in a one-hand grip posture (183.76gf), the maximum touch pressure was higher than in a both-hand grip posture (158.92gf), and the difference was statistically significant (Figure 6). This is probably because the pressing strength of a thumb is greater than that of a forefinger and other fingers support the thumb when it presses the button in a one-hand posture.

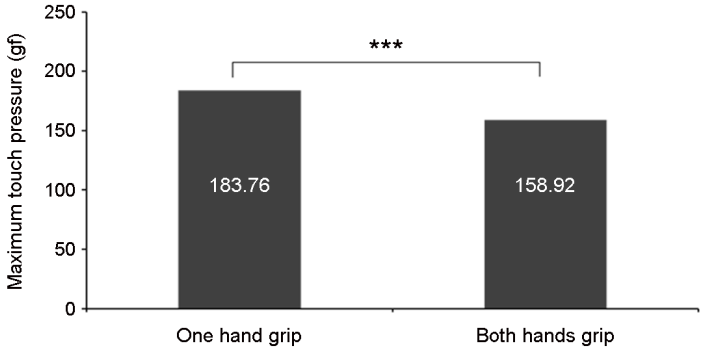


Figure 6. Maximum touch pressure for each posture

For the touch interaction type which showed significant difference, the Tukey test was conducted as a post-hoc test. As a result, there was significant difference between Tap/Long Press and 3D Touch on the significance level of 1%, and 3D Touch showed the highest maximum touch pressure (318.98gf) (Figure 7). This is probably because participants' conceptual thinking that 3D Touch press motions would need much strength affected their press behaviors. The touch pressure of Long Press (157.12gf) was higher than that of Tap (37.92gf) probably because participants' experience and habit of using smart phones developed a motor schema for each touch interaction and induced them to apply more strength to Long Press than Tap.

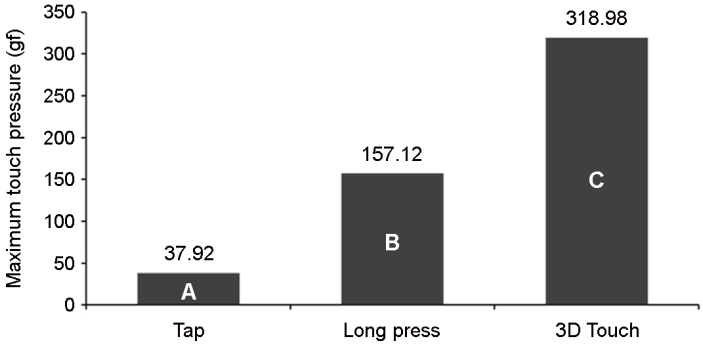


Figure 7. Maximum touch pressure for each touch type

A simple effect analysis was conducted on the user posture that involved interactions and touch interaction types. As a result, there was difference depending on touch interactions on the significance level of 5%. As shown in Figure 8, the maximum touch pressure in a one-hand posture was higher than that in a both-hand posture in general. Particularly in Long Press, the difference was more significant.

5.1.2 Press duration

A variance analysis was conducted to examine the effect of independent variables, and there was significant difference depending on touch interaction types on the significance level of 1% (Table 3).

The Tukey test was conducted as a post-hoc test on touch interaction types that showed significant difference. As a result, significant

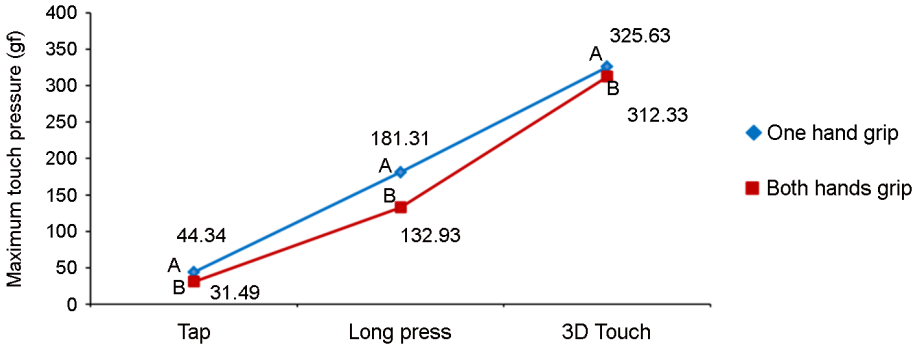


Figure 8. Maximum touch pressure by grip posture and touch type

Table 3. ANOVA summary table of press duration

Source	DF	SS	MS	F	Pr>F
Posture	1	0.0062	0.006	0.11	0.742
Gender	1	0.004	0.004	0.07	0.798
Touch type	2	25.354	12.677	221.83	0.000***
Posture x Gender	1	0.077	0.077	1.36	0.246
Posture x Touch type	2	0.012	0.006	0.11	0.897
Gender x Touch type	2	0.145	0.073	1.27	0.284
Posture x Gender x Touch type	2	0.048	0.024	0.42	0.660
Errors	168	9.601	0.057		
Total	179	35.247			

*p<0.1, **p<0.05, ***p<0.01

difference was shown in Tap/Long Press and 3D Touch on the significance level of 1%, and the longest press duration (1.01sec) was measured from Long Press (Figure 9). This is probably because participants' experience of Long Press that usually took more time developed a motor schema and induced them to press for a longer time. As for 3D Touch motions (0.60sec), they pressed for a longer time than Tap (0.10sec) probably because participants applied much strength for 3D Touch motions, which caused high pressure, and resulted in extending the time linearly.

5.2 Press behavior characteristics of 3D touch and long press depending on whether there is a feedback

5.2.1 Maximum touch pressure

A variance analysis was conducted to examine the effect of independent variables. According to the result, there was significant difference depending on whether there was a feedback and the touch interaction type on the significance level of 1%, and there was interaction depending on whether there was a feedback and the touch interaction type on the significance level of 1% (Table 4).

As for significant difference depending on whether there was a feedback, the maximum touch pressure when there was a feedback

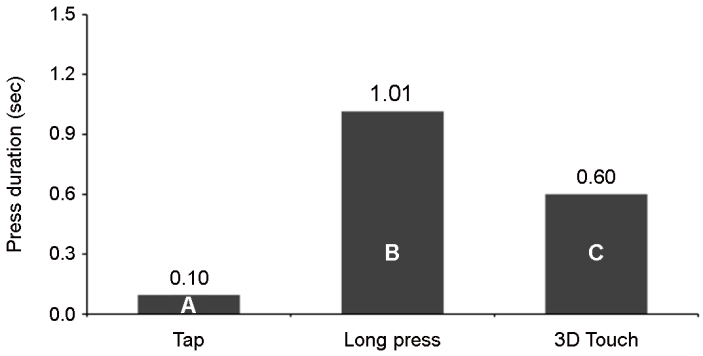


Figure 9. Press duration for each touch interaction type

Table 4. ANOVA summary table of maximum touch pressure

Source	DF	SS	MS	F	Pr>F
Feedback	1	266584	266584	131.80	0.000***
Touch type	1	314690	314690	155.58	0.000***
Feedback x Touch type	1	105994	105994	52.40	0.000***
Errors	116	234635	2023		
Total	119	921903			

*p<0.1, **p<0.05, ***p<0.01

(143.78gf) was lower than that when there was no feedback (238.05gf) (Figure 10). This is probably because participants recognized that the function was executed upon receiving a feedback and then applied no more strength but took the finger off the screen immediately (Release).

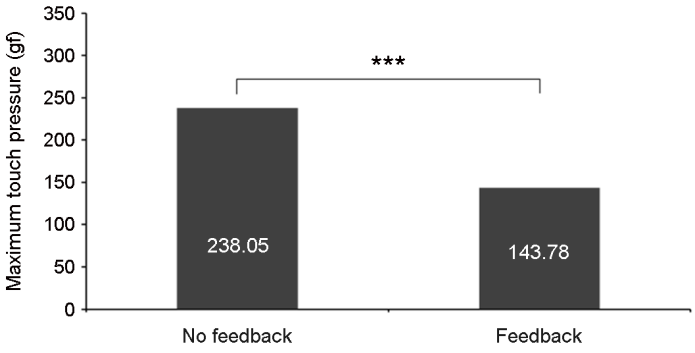


Figure 10. Maximum touch pressure by feedback type

A simple effect analysis was conducted on touch interaction types and whether there was a feedback in relation to interactions. The result shows that there was significant difference in maximum touch pressure depending on whether there was a feedback

and depending on the touch interaction type on the significance level of 1% (Figure 11). When there was a feedback, Touch pressure decreased in both Long Press and 3D Touch, and the decrease rate of 3D Touch was higher than that of the other. As the maximum touch pressure of 3D Touch was a bit higher than 150gf, the critical pressure value, this is probably because participants applied no more strengthen when given a feedback to the applied critical pressure and then took the finger off the display surface (Release).

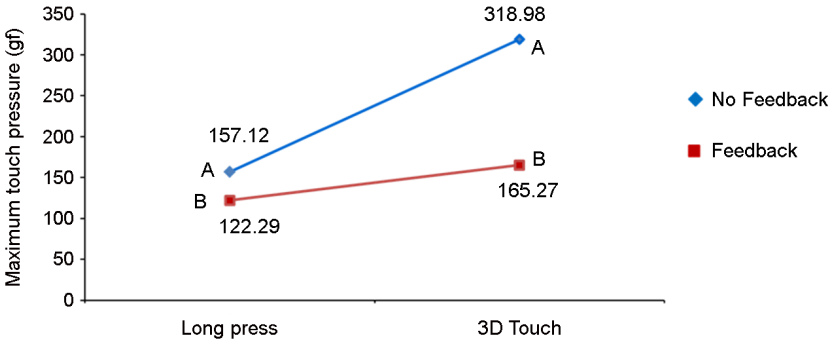


Figure 11. Maximum touch pressure by feedback and touch interaction type

5.2.2 Press duration

As for press duration, there was significant difference depending on touch interactions on the significance level of 1%, and there was interaction depending on whether there was a feedback and the touch interaction type on the significance level of 1% (Table 5).

Table 5. ANOVA summary table of press duration

Source	DF	SS	MS	F	Pr>F
Feedback	1	0.0364	0.0364	0.78	0.378
Touch type	1	9.0423	9.0423	193.94	0.000***
Feedback x Touch type	1	0.5587	0.5587	11.98	0.001***
Errors	116	5.4084	0.0466		
Total	119	15.0458			

*p<0.1, **p<0.05, ***p<0.01

A simple effect analysis was conducted on whether there was a feedback and the touch interaction type in relation to interactions. The result shows that there was significant difference in press duration depending on whether there was a feedback and the touch interaction type on the significance level of 5% (Figure 12). When there was a feedback, the press time of Long Press was extended while that of 3D Touch was shortened. This is because most participants would take the finger off the screen (1.19sec) when given a feedback at the critical time point (0.8sec) after pressing the button. When there was no feedback (1.01sec), few took the finger off earlier than the critical time (0.8sec), and thus the duration was relatively long. In contrast, a feedback was given when the critical pressure reached 150gf in the case of 3D Touch, and then participants would take the finger off with no more strength applied

(0.50sec). Hence, the press duration was shorter than that when there was no feedback (0.60sec).

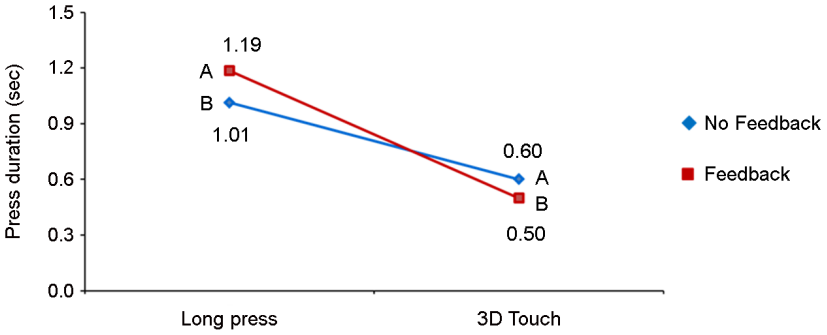


Figure 12. Press duration by feedback and touch interaction type

5.3 Press behavior characteristics of 3D touch and long press depending on touch areas in a one-hand grip posture

5.3.1 Maximum touch pressure

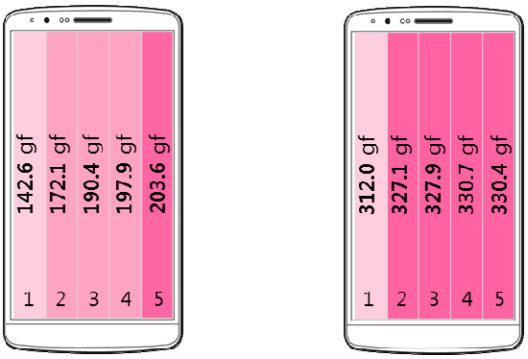
A variance analysis was conducted to examine the effect of independent variables. The result shows that there was significant difference depending on touch areas and touch interaction types on the significance level of 1% (Table 6).

Table 6. ANOVA summary table of maximum touch pressure

Source	DF	SS	MS	F	Pr>F
Touch location	4	61807	15452	5.33	0.000***
Touch type	1	1561975	1561975	538.81	0.000***
Touch location x Touch type	4	18415	4604	1.59	0.177
Errors	290	840693	2899		
Total	299	2482890			

*p<0.1, **p<0.05, ***p<0.01

The Tukey test was conducted as a post-hoc test on touch areas that showed significant difference. As a result, there was significant difference between the 1st row and 2nd to 5th rows on the significance level of 1% in the case of 3D Touch. As for Long Press, there was significant difference between the 1st row and the 5th row on the significance level of 5% (Figure 13). As shown in Figure 14, since the thumb gets farther from the fingering range in a one-hand grip posture (right hand), the thumb needs to be stretched further to press the spot. As the angle of pressing in the Z-axis becomes farther from the right angle to the display, the applied strength is relatively small. Hence, as the spot gets farther from the fingering range, the maximum touch pressure decreases accordingly.



(a) Long press (b) 3D Touch

Figure 13. Maximum touch pressure by touch location

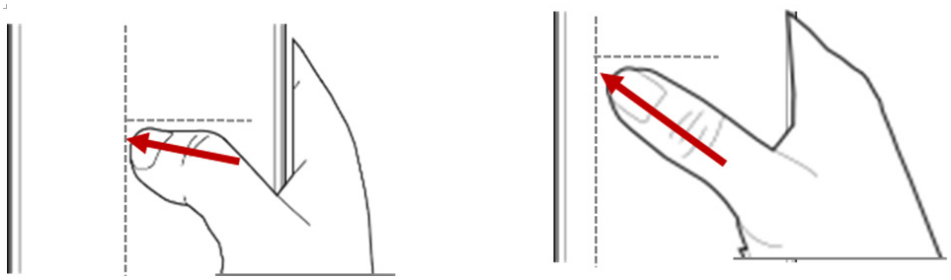


Figure 14. Angle between pressing finger and z-axis for different fingering distances

5.3.2 Press duration

A variance analysis was conducted to examine the effect of independent variables. According to the result, there was difference depending on the touch interaction type on the significance level of 1%, but there was no significant difference depending on the touch area (Table 7).

Table 7. ANOVA summary table of press duration

Source	DF	SS	MS	F	Pr>F
Touch location	4	0.005	0.001	0.02	0.999
Touch type	1	12.830	12.830	161.57	0.000***
Touch location x Touch type	4	0.011	0.003	0.03	0.998
Errors	290	23.028	0.079		
Total	299	35.874			

*p<0.1, **p<0.05, ***p<0.01

6. Conclusion

This study examines differences in press behavior characteristics of each touch interaction for 3D Touch which is highly probable to be established as a new touch interaction of smart phones with the aim to prevent interference with existing touch interactions—Tap and Long Press—so that users can easily distinguish them and have no problems in using both 3D Touch and existing interactions.

According to the experiment result, the press behavior characteristics were as follows:
With no feedback given, participants tended to press 3D Touch at relatively high pressure over 318.98gf for 0.60sec; they tended to press Long Press at the pressure of 157.12gf for 1.01sec; and they tended to press Tap at pressure as low as 37.92gf for a relatively short time around 0.10sec.

As for the distribution of maximum touch pressure over touch interactions, there was an area of intersection between 3D Touch and Long Press around 200 to 300gf (Figure 15).

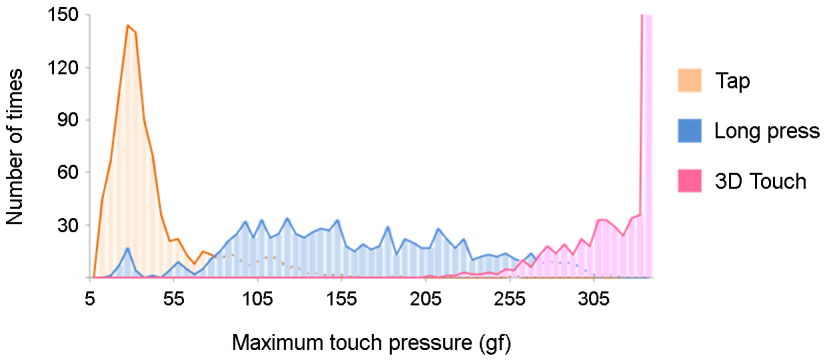


Figure 15. Distribution of maximum touch press for each touch interaction with no feedback

As for the distribution of press duration over touch interactions, there was an area of intersection between 3D Touch and Long Press around 0.4 to 1.4 seconds (Figure 16).

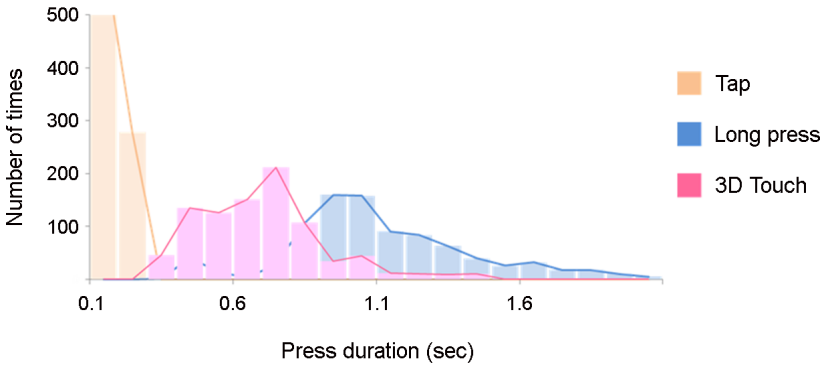


Figure 16. Distribution of press duration for each touch interaction with no feedback

There was an area of intersection between 3D Touch and Long Press in terms of touch pressure and time distribution probably because of the similarity between the two motions in terms of press behavior. This indicates that when 3D Touch and Long Press are mixed for the same UIs, there could be interference, which may make it difficult to distinguish the two motions.

However, press behaviors of 3D Touch and Long Press when there was a feedback given were different from those when there was no feedback given. As for 3D Touch, when there was a feedback at the critical pressure of 150gf, the maximum touch pressure was 157.12gf, which is 161.86gf lower than when there was no feedback (318.98gf). The press duration was 0.50sec, which is 0.10sec shorter than when there was no feedback (0.60sec). As for Long Press, when there was a feedback given at the critical time of 0.8sec, the maximum touch pressure was 122.29gf, which is 34.83gf lower than when there was no feedback (165.27gf). The press duration was 1.19sec, which is 0.18sec longer than when there was no feedback given (1.01sec).

As for the distribution of the maximum touch pressure of the two touch motions when there was a feedback given, there was an area of intersection between 3D Touch whose critical pressure was 150gf and Long Press whose critical time was 0.8sec around 90 to 310 gf (Figure 17). This indicates that the maximum touch pressure of 3D Touch drastically decreased compared to when there was no feedback, increasing the probability of interference with Long Press.

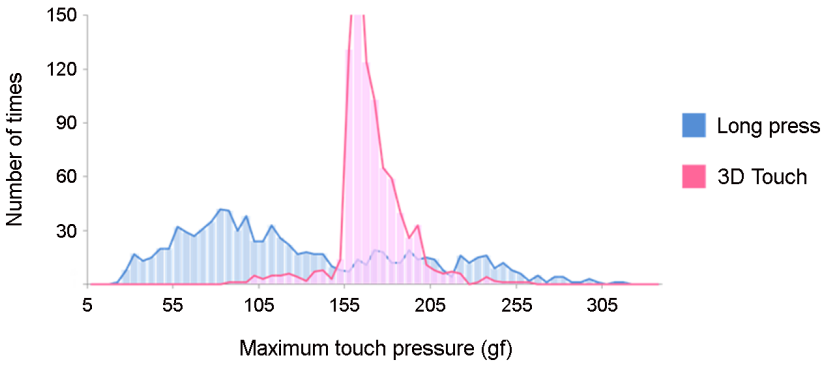


Figure 17. Distribution of maximum touch press for each touch interaction with feedback

As for the distribution of press duration of the 2 touch motions when there was a feedback, there was an area of intersection between 3D Touch whose critical pressure was 150gf and Long Press whose critical time was 0.8sec around 0.6 to 1.2sec (Figure 18), which indicates that the press duration of 3D Touch was shortened and that of Long Press was extended compared to when there was no feedback. As a result, the probability of interference between the two motions decreased.

As a feedback is given at the point of the specific critical value, behavior characteristics of touch interactions can be calibrated, and then the probability of interference between 3D Touch and Long Press may be different depending on the critical pressure of 3D Touch. Hence, errors of 3D Touch and Long Press can be minimized as long as a proper level of 3D Touch critical pressure is set with a feedback given.

As for the maximum touch pressure depending on the smart phone user posture, the pressure when the screen was pressed with the thumb in a one-hand grip posture (183.76gf) was 24.84gf higher than when the screen was pressed with the forefinger in a both-hand grip posture (158.92gf). There was difference in touch pressure depending on the user posture, which indicates that the probability of interference between 3D Touch and Long Press may be different depending on touch pressure. Since the duration of certain postures may be different depending on the smart phone size, adjusting critical pressure settings of 3D Touch accordingly

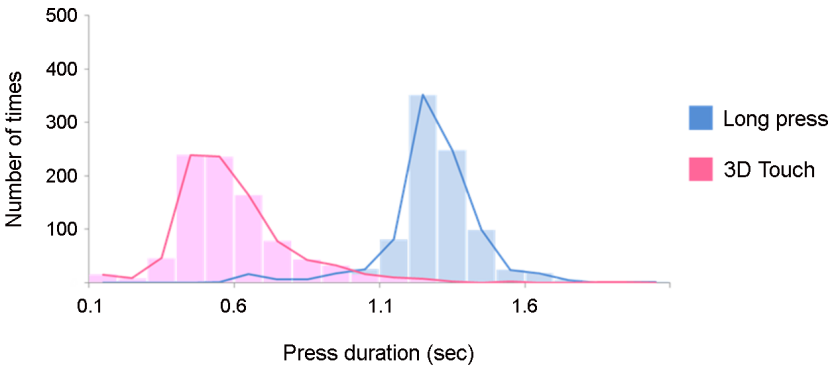
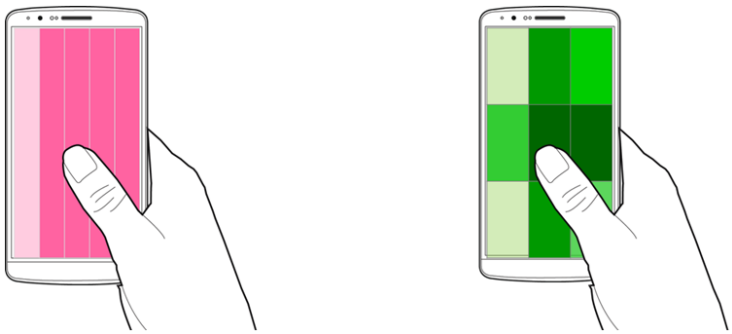


Figure 18. Distribution of press duration for each touch interaction with feedback

also can be taken into consideration. For instance, a smart phone of relatively small size would be convenient for a one-hand grip posture, and thus it is highly probably that the user maintains a one-hand posture while using the smart phone. In this case, critical pressure settings of 3D Touch advantageous for a one-hand grip posture can be effective to minimize interference with Long Press.

As for the maximum touch pressure of 3D Touch depending on the touch spot, there was difference between the 1st row and the 2nd to 5th rows when the right hand was used. This result corresponds to an existing research (Parhi et al., 2006) suggesting that the 1st row, which is relatively far from the fingering range, is of high inconvenience while the 2nd row, which is within the fingering range and relatively easy to reach, is of low inconvenience (Figure 19). Since the 1st row is at a farther spot of the fingering range, the angle between the screen and the finger in the Z-axis is close to horizontality and thus the applied pressure is relatively low. Besides, as the spot is at a farther spot of the fingering range and hard to reach, the level of inconvenience is high. However, the rightmost area showed different results: Since the 5th row is close to the gripping hand, the area is hard to reach and thus the level of inconvenience is high as well. Besides, the maximum touch pressure was not low probably because the angle between the screen and the finger in the Z-axis is close to a right angle and thus much strength is applied regardless of the level of inconvenience



(a) Maximum touch pressure of 3D touch (b) Comfort rating

Figure 19. Maximum touch pressure and comfort rating for each region

The fact that there is difference in touch pressure depending on the touch spot indicates that there might be difference in the

probability of interference between 3D Touch and Long Press depending on the touch spot. For smart phones small enough for a one-hand grip, therefore, adjusting critical pressure settings of 3D Touch depending on the touch spot can be effective in minimizing interference.

No difference in press behavior depending on the gender was found. This is probably because there was little difference in pressing strength between men and women since the touch interaction required an elaborate manipulation rather than much strength.

This study examines press behavior characteristics of 3D Touch, which is a new interaction, and two existing touch intersections—Long Press and Tap. The result indicates that there is a risk of interference between 3D Touch and Long Press. When there is a feedback given at a specific critical value, however, press behaviors of 3D Touch and Long Press can be calibrated. Hence, it is expected that a proper setting of critical pressure for 3D Touch can minimize such interference even if 3D Touch and Long Press are mixed for the same UIs. In addition, it turned out that there was difference in press behaviors depending on grip postures and touch spots, and that the proper critical pressure value of 3D Touch might be different depending on the smart phone size and touch spot. These findings can be utilized as a basis for designing the optimal critical value of 3D Touch at which users can easily distinguish 3D Touch from existing touch interactions.

This study examines the difference in user press behavior characteristics depending on the touch interaction type. The future study needs to find out the optimal value to minimize errors in Long Press by adjusting settings depending on the critical pressure condition of 3D Touch based on the findings of this study. In addition, since elaborate pressing motions may be difficult to middle-aged and elderly people, the future study also needs to examine press behavior characteristics specifically for users in such age groups.

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