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Evaluation of Nano-stick, Foam Buttons, and Other Input Methods for Gameplay on Touchscreen Phones

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Abstract Two user studies evaluated gameplay on a touchscreen phone. A "run and gun" study compared a nano-stick, foam buttons, a soft gamepad, and a *Wii Remote*. User performance was measured using *Metal Slug* on an *Android* phone. The *Wii Remote* performed best (fewer player deaths, lower completion times), the soft gamepad worst. The nano-stick was second best, but was rated on a par with the *Wiimote* by participants. The second study used a fighting game. The same input methods (minus the foam buttons) were tested for the number of successful combos. No significant differences were observed between the input methods. Comfort and suitability of the nano-stick were praised by participants in the freeform feedback.

***Keywords*:** Tactile feedback, touchscreens, game input, joystick, gamepad, performance evaluation

1. Introduction

Popularized by the Apple *iPhone* in 2007, touchscreen devices are now ubiquitous. These devices have just a few physical buttons, relying instead on touch and accelerometer input. Among popular applications are video games. Since classical gameplay is not fully supported, developers employ soft on-screen controllers (Fig. 1) where translucent soft controls overlay the game scene. However, such controls are inferior to physical controls (Wong et al., 2010; Zaman et al., 2010).

Fig. 1. Scene *Metal Slug−Super Vehicle−001* showing the soft gamepad controller buttons.

Hardware solutions exist but there is no standard approach to game input on touchscreen devices. In this paper we present a new input device for touchscreen phones. *Nano-stick* is a miniature version of a joystick used for tablet computers. We describe the design of nano-stick and an evaluation of its effectiveness for gameplay. We also present and evaluate an additional novel input method: *foam buttons*.

2. Gameplay Evaluation

Our work builds on gameplay evaluation, tactile feedback, and techniques for gaming on phones. Gameplay controllers can be evaluated using the ISO 9241-9 standard for non-keyboard input devices.

Such an evaluation was reported by Natapov et al. (2009) who compared the *Wii Remote*, the Nintendo *Classic Controller,* and a mouse. This style of evaluation is relevant for home entertainment systems where point-select tasks are common or if the device is used for camera control. However, interaction with games of the "beat 'em up" genre is best evaluated using real or simulated gameplay.

Much of the research in computer games focuses on user experience with game content, interactivity, etc. Bodén et al. (2007) were among the first to examine user performance. They presented a study comparing stylus and button input for mobile games. They found higher scores with buttons.

Zaman et al. (2010) compared the soft gamepad of Ubisoft's *Assassin's Creed: Altair's Chronicles* on Apple's *iPhone 3G* with the hard gamepad of Nintendo's *DS*. Player deaths were 2.5× higher on the *iPhone* than on the *DS*, and the completion time was 1.4× slower.

Wong et al. (2010) informally evaluated players' performance using soft and hard keypads while playing *Capture*. The authors reported higher participant scores with the keypad.

In Fritsch et al.'s (2008) study, participants used a PC, a Nintendo *DS*, and a mobile phone while playing *Prince of Persia*, *Age of Empire*, and *Call of Duty*. The phone was slowest. This was attributed to the particular phone, which included a physical numeric keypad and two soft buttons.

Novel input methods are also possible. Gilbertson et al. (2008) used a mobile phone and compared physical buttons with tilt input using *Tunnel Run*, a 3D first-person driving game. Participants preferred the tilt interface. Arguments for use of tilt input are also reported by Chehimi and Coulton (2008).

3. Input Devices for Gaming on Touchscreen Phones

In this section, we summarize the most notable gaming devices for touchscreen phones. Using a joystick for game input is not novel. The *Joystick-it* (Web-1) tablet stick adds tactile feedback on *Android* tablets and the Apple *iPad* (Fig. 2a). Using a suction cup, the device attaches to the touchscreen above the soft D-PAD. The physical stick is used like an arcade stick.

Fig. 2. (a) *Joystick-it*, (b) Logitech *iPad Joystick*, (c) Joystickers *Classics*, (d) Sony Ericsson *Xperia Play*, (e) *iControlPad*.

The *Fling Game Controller* (Web-2) uses a conductive sliding button instead of a stick (Fig. 2b). The button slides within a plastic spiral. Releasing the button returns it to the center of the spiral (see also Web-3). Joystickers *Classics* (Web-4) is yet another idea (Fig. 2c). It uses onscreen physical buttons attached using a suction cup.

Sony Ericsson offers *Xperia Play* (Web-5), a touchscreen smartphone with a sliding controller (Fig. 2d) (see also Web-6). *iControlPad* (Web-7) is a physical controller with a recess to accept the user's phone (Fig. 2e). With the phone in the recess, the device behaves like a handheld game console.

4. Motivation

Our user studies address a few shortcomings in previous work. The studies by Wong et al. (2010) and Fritsch et al. (2008) were informal with substantial differences between conditions. While the work by Zaman et al. (2010) employed formal analysis, there are limitations. In their work, the screen size of the Nintendo *DS* was different from the screen size of Apple *iPhone 3G*. The devices were used for both input and output. In contrast to the work by Natapov and MacKenzie (2010), the study by Zaman et al. (2010) involved only a single game task, making it difficult to generalize results to other gameplay styles. Finally, no new input devices were introduced. We attempt to address these shortcomings herein.

5. User Study I

Participants. Twelve unpaid participants (three females) between 19 and 30 years (μ = 26.2) were recruited from the local university. Participants reported on average 5.2 hr/week of gameplay. Eight participants used touchscreen devices as their primary phone. None had previous experience with the games in the study. Also, none had previous experience with the nano-stick or foam buttons.

Apparatus. A Google *Nexus One* phone was used. The phone connected to a laptop using a USB cable. This connection charged the battery and allowed taking screen snaps and logging touchscreen events. Fig. 3 shows the four input methods: a soft gamepad, a nano-stick, foam buttons, and a *Wii Remote* (*Wiimote*).

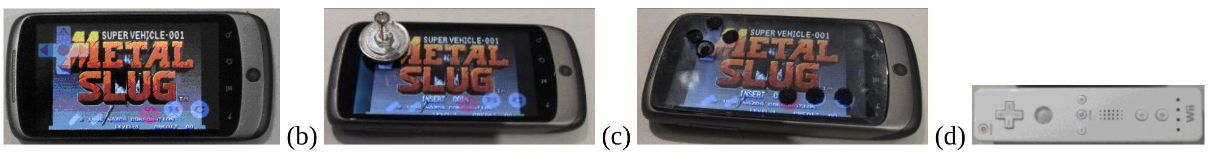
(a) (b) (c) (d)


Fig. 3. Input methods used in the study. (a) Soft gamepad. (b) Nano-stick. (c) Foam buttons. (d) *Wiimote*.

Nano-stick. Our nano-stick was inspired by *Joystick-it* (Fig. 2a). As the *Joystick-it* is for large-screen tablets, we built a miniature version suitable for a 3.7” touchscreen. A hole was drilled in the center of a 25 mm coin. A 2 mm layer of conductive foam was glued to one side of the coin. A 6−32 × ¾” metal screw was put on the reverse side of the coin through the hole in the center. A nut and a washer were fixed 20 mm below the tip of the screw to secure the coin. A suction cup, 15 mm in diameter, was glued to the screw on the other side of the coin (the same side of the coin with the foam). See Fig. 4.

Fig. 4. Close-up of the nano-stick.

The device functions as follows. The nano-stick is positioned in the middle of the soft D-PAD. Tilting the screw creates contact between the foam and the touchscreen. All the materials, besides the suction cup, are conductive. The foam is spongy, so the contact area increases as pressure increases. This effectively imitates the touch of a human finger. The user’s other hand (holding the device) receives tactile feedback as the foam gets compressed and decompressed due to pressure. Additional feedback is provided by the suction cup which “pushes back” as the screw is tilted. The suction cup also serves to reposition the screw to a neutral position when the screw is released.

Foam buttons. We also evaluated stick-on foam buttons. The buttons were made from conductive foam and glued to a screen protector over soft buttons A, B, C, and the soft D-PAD buttons (Fig. 3c). The sponginess of the foam creates the tactile sensation of pressing real physical buttons. The edges and the circumferences of the left and down buttons were covered with vinyl electric tape to reduce the contact area with the thumb and avoid inadvertent triggers.

Wiimote. The last evaluated input method employed the *Wiimote* communicating via a Bluetooth driver. The setup is similar to the *iControlPad* described earlier.

Games and emulation. *Metal Slug* is made for the *Neo-Geo* platform and can be played on any system with *MAME* (Multiple Arcade Machine Emulator) and *Neo-Geo* BIOS. An *Android* application called *TigerArcade*, which allows *MAME* emulation, was also used. (*MAME* is a platform having tens of thousands of games available.) This allowed us to explore different experimental design alternatives.

Besides, *TigerArcade* is fully customizable with the *Wiimote* and supports three different sizes of soft D-PAD controllers.

Participants played the first mission from *Metal Slug−Super Vehicle−001* (Fig. 1). This is a "run and gun" arcade game, dating to 1996. The player jumps to and from platforms, averts obstacles, shoots enemies, etc. The game features a number of missions, each ending when a "boss" is defeated.

Procedure. Participants were asked to complete the first mission of *Metal Slug* three times for each input method using as few lives as possible. Logging started with the first button press at the beginning of each block and ended when the boss was defeated. For each block, the number of player deaths was logged. Participants were free to hold and position the device in a manner comfortable to them.

For each input method, participants were briefed on the operation and were allowed 30 seconds of practice. The *Wiimote* button mappings were 1 → shoot, 2 → jump, and a → grenade throw. For the other conditions, the mappings were A → shoot, B → jump, and C → grenade throw. At the end, participants filled out a questionnaire to rate the devices.

Game strategies. There are a number of strategies to improve performance, such as freeing prisoners and using a tank. These are either known or discovered with experience. Space precludes a full description here.

Design. The intent was to investigate how the input methods compare when playing *Metal Slug* on a 3.7" touchscreen phone. The experiment was a 4 × 3 repeated measures design. The independent variables were input method (soft gamepad, nano-stick, foam buttons, *Wiimote*) and block (1, 2, 3). The dependent variables were mission completion time, number of player deaths, and score.

Participants were divided in four groups of three with input method administered following a balanced Latin square. Testing took about one hour per participant.

6. Results and Discussion

Mission completion time. Means for mission completion time were 211 s (soft gamepad), 196 s (nano-stick), 200 s (foam buttons) and 176 s (*Wiimote*). The main effect of input method on mission completion time was statistically significant, as revealed in Friedman's test ($\chi^2_3 = 13.8$, $p < .005$) (Fig. 5a). The block effect was also significant ($\chi^2_2 = 9.9$, $p < .01$) (Fig. 5b).

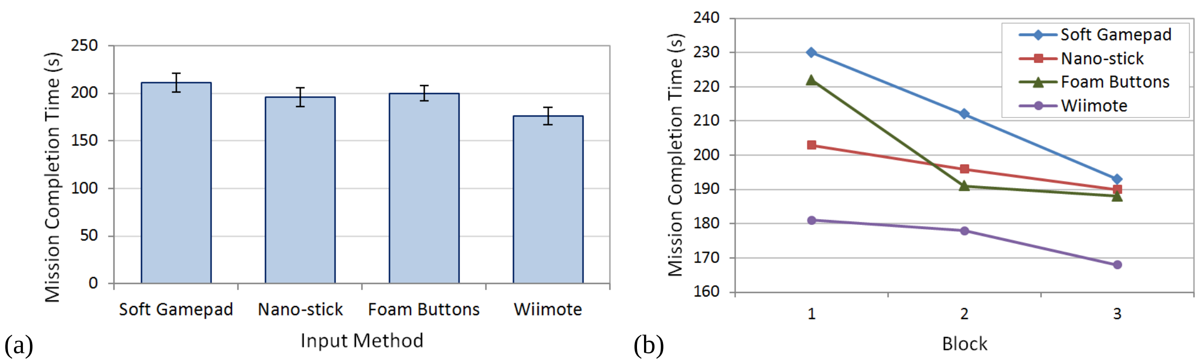


Fig. 5. Mission completion time (a) by input method (b) by block. Error bars show ±1 *SE*.

Player deaths. Means for number of player deaths were 6.3 (soft gamepad), 4.5 (nano-stick), 5.0 (foam buttons) and 3.3 (*Wiimote*). The main effect of input method on player deaths was statistically significant ($\chi^2_3 = 19.72$, $p < .001$) (Fig. 6a). The lower count with the *Wiimote* indicates that it was easier to dodge the attacks of the enemies. The block effect was also significant ($\chi^2_2 = 7.49$, $p < .05$) (Fig. 6b).

In line with previous work (Zaman et al., 2010), improvement was observed over blocks for all input methods. This indicates that the task allowed us to observe differences in participants' performance across input methods. Also, in the work cited, the soft gamepad had one of the worst performances.

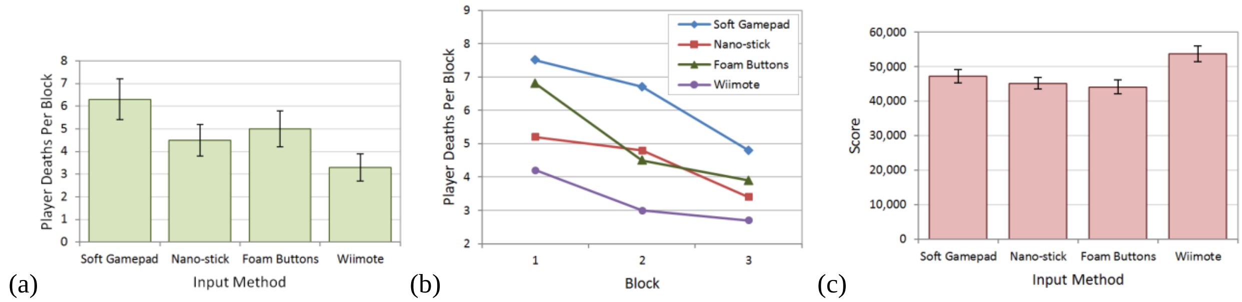


Fig. 6. (a) Player deaths per block for each input method. (b) Player deaths by block. (c) Score by input method. Error bars show ±1 *SE*.

Score. Means for score were 47,205 (soft gamepad), 45,156 (nano-stick), 44,104 (foam buttons) and 53,717 (*Wiimote*). The main effect of input method on score was statistically significant ($F_{3,24} = 6.8$, $p < .005$) (Fig. 6c). The main effect of block was not significant ($F_{2,16} = 2.53$, $p > .05$).

Employing certain game strategies drastically improves the score, but participants had to discover these strategies. Still, a participant who just "gets through" without freeing prisoners and using the tank will finish the mission. In fact, this was not observed, as participants were motivated to free prisoners to get rewards and keep the tank, which allowed them to avoid unnecessary player deaths and to access to the tank's gun (the most rewarding outcome in terms of score). The results show that this was achieved easiest with the *Wiimote*.

Performance summary. Overall, the results indicate that the *Wiimote* was the best performing device. Using the *Wiimote*, the player character was killed less often, less amount of time was required to complete the mission, and higher scores were obtained. An analysis of button presses indicated that fewer button presses were required for shooting, jumping, and grenade throwing. The nano-stick was found competitive to the *Wiimote*. On the other hand, the soft gamepad and the foam buttons performed worst.

Even though the *Wiimote* performed best, use of a separate input controller is simply not viable in many (most!) scenarios for gameplay on a touchscreen phone. Clearly, users must decide between playability and portability. The portability and good performance of the nano-stick makes the device an attractive alternative.

Feedback from participants. Participants were asked to rank each input method on a Likert scale from 1 (worst) to 7 (best) for accuracy, responsiveness, comfort, and overall impression. Although the *Wiimote* was consistently rated higher in each category, the nano-stick was rated higher than the gamepad in terms of comfort and overall impression. In the comfort category the nano-stick was also rated higher than the foam buttons. Overall, the nano-stick and the *Wiimote* were rated equally high.

We also solicited open-ended comments. One participant felt that the foam buttons were misleading as the design suggested they should be pressed, but, in reality, only touching was necessary. Another participant reported the opposite, saying that the foam buttons provide considerable usability because of the tactile feedback they provide. Yet another participant pointed out that the soft gamepad method occluded the screen. Finally, a participant who happened to be highly experienced with game controllers pointed out that, unlike the *Wiimote*, the foam buttons do not allow smooth sliding of the thumb between the buttons on the D-PAD.

The results of the first user study motivated us to investigate how these results apply to other settings, such as the *Street Fighter* series of video games.

7. User Study II

Participants. Twelve unpaid participants (two females) between 19 and 32 years ($\mu = 26.6$) were recruited for the study. The participants were screened for having expertise in fighting video games. On a scale of 1 to 7 all participants ranked their familiarity with fighting games as 3 or higher. Eleven participants were familiar with *Street Fighter*. Participants reported on average 7.6 hr/week playing video games. None of the participants had touchscreen experience with *Street Fighter* or with the nano-stick.

Apparatus. The hardware was the same as in the first user study (minus the foam buttons).

Game, Characters, Combos. We chose the 1998 game *Street Fighter Zero 3* by CAPCOM (aka *Street Fighter Alpha 3*). This game is appropriate since a typical *Street Fighter* move involves a sequence of D-PAD button presses or thumb slides followed by a single press of an action button. Therefore, the strong emphasis on the D-PAD makes the game well suited to discriminating the input methods.

A typical *Street Fighter* single-player gameplay can be described as follows. The player selects an on-screen character and engages in close combat matches with an opponent. Two of three rounds must be won to continue. After all opponents are defeated, the player must defeat a few boss characters to win the tournament. The player gets an opportunity to change the character if defeated in a match.

In fighting games, producing a *combo* is critical. A combo is a sequence of actions with strict timing limitations yielding a cohesive series of hits. Producing combos requires a responsive and accurate input device and high player expertise. In *Street Fighter*, each character has a set of combos that must be learned. There are 25 characters to choose from in *Street Fighter Zero 3*. We chose the characters and combos below. (The combos are performed by the sequences indicated.)

- Ryu's Fireball (Hadouken): ↓↘→+a
- Chun-Li's Fireball (Kikouken): ←↙↓↘→+a
- E. Honda's Sumo Headbutt: $\leftarrow_{HOLD}$ →+a

These three characters (Ryu, Chun-Li and E. Honda) are among the most known and popular in the series and the chosen combos are among the "signature" combos of the characters. Any participant with *Street Fighter* experience would be familiar with the characters and the combos. This was important, as the majority of the recruited participants were familiar with *Street Fighter* and the learning effect due to task was thus minimized.

Fig. 7. *Street Fighter Zero 3*. Ryu fighting Chun-Li.

Procedure. Participants were allowed about one minute to practice each condition. For each input method and combo we recorded 50 attempts. We determined in the pilot that shortly after 50 attempts either the participant's character would be beaten, or the participant would beat the CPU-controlled opponent. At this point the participant must restart the match. We wanted to minimize the need for restarts as it was distracting and time consuming to participants. And so, we allowed 50 attempts.

We developed custom software to log button presses from *TigerArcade*. Since each of the three combos ended with the press of the A, B, or C button, our application counted the number of presses of these buttons since the beginning of each match. Each press was thus considered an attempt at the combo. After 50 presses, the application played a sound signaling the end of block. Throughout each block, the invigilator observed the participant performing the combo. Each successful outcome was logged manually. Producing a successful combo was also accompanied by an audio cue. This helped to ensure the accuracy of the log.

Participants were asked to produce the combo repeatedly. The opponent was an NPC (non-player character) controlled by the CPU. Participants were told to concentrate on the combo without trying to block attacks by the opponent. Nonetheless, some participants chose to block, but this did not interfere with the logging of results.

If the participant fails to block an attack of the opponent, the participant's fighting character comes under attack. During this period, attempts by the participant to fight back are ignored until the opponent is finished inducing damage. Even if a successful sequence of buttons were produced, it would be impossible to know. Therefore, false counting could occur during this period. Participants were informed not to press action buttons while under attack. A few participants were observed violating this request, and in such cases the following was done. Our software played a special sound when either action button was pressed providing a cue to the invigilator. If participants were found pressing action buttons while under attack, the invigilator marked the attempt as ignored with the help of the audio cue. After the block was finished, the invigilator asked the participant to redo the ignored attempts.

Participants were also prevented from performing moves other than blocking and the combo required to complete the block.

Design. The goal was to compare the input methods for making combos in *Street Fighter* on a touchscreen phone. The experiment was a 3 × 3 repeated measures design. The independent variables were input method (soft gamepad, nano-stick, *Wiimote*) and special move (Hadouken, Kikouken, Sumo Headbutt). The dependent variable was the number of combos over 50 attempts.

8. Results and Discussion

The means for number of combos by input method were 20 (soft gamepad), 17 (nano-stick), and 20 (*Wiimote*). Means by special move were 21 (Hadouken), 14 (Kikouken), and 23 (Sumo Headbutt). See Fig. 8. The main effect of input method on combos was not statistically significant ($F_{2,22} = 1.02$, $p > .05$). The effect of special move on combos was, however ($F_{2,22} = 5.4$, $p < .05$). This suggests that all input methods provide similar performance for producing combos in *Street Fighter*. Furthermore, a pair-wise analysis revealed that Kikouken combos were harder to produce than Sumo Headbutt combos. This comes as no surprise since Kikouken requires a longer half circle slide on the D-PAD.

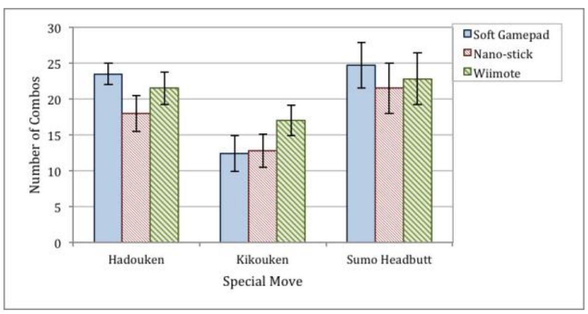


Fig. 8. Number of combos by special move. Error bars show ± 1 *SE*.

The fact that all participants were skilled may also explain why no significant difference was found, as expert users are better than novices and have more options available to them due to prior knowledge of the task. But, due to the complexity of the task in the second study, choosing novice participants was not an option, since the learning curve for combos is too steep. We can conclude, therefore, that all three input methods provide similar performance for the fighting game used in the study.

Feedback from participants. Participants were asked to rank each input method using the same scheme as in User Study I. Again, the *Wiimote* was consistently rated higher in each category, except for comfort, where it was rated equally with the nano-stick. The nano-stick was rated higher than the gamepad in each category.

9. Conclusion

We conducted two evaluations of game input methods on a touchscreen phone. In the first user study participants played the first mission from *Metal Slug−Super Vehicle−001*. Four input methods were evaluated: soft gamepad, nano-stick, foam buttons, and the *Wiimote*. The number of player deaths was 48% lower with the *Wiimote* compared to the soft gamepad. Mission completion time was 17% less with the *Wiimote* when compared to the soft gamepad. Overall, the nano-stick was comparable to the *Wiimote*. The soft gamepad had the poorest performance. In line with the findings, the nano-stick and the *Wiimote* were the most preferred input methods and the soft gamepad was least preferred.

The second user study used a fighting game, where expert users produced combo moves. All the input methods except the foam buttons were re-used and the number of combos was measured. No significant difference was found between input methods. However, it was noted in freeform feedback that the nano-stick does not have the deficiencies of the other two methods. Two participants highlighted the comfort and suitability of the nano-stick for fighting games. The soft gamepad received praise for better than expected performance. The small size of the screen causing occlusion and lack of tactile feedback are among other reasons that make the soft gamepad unattractive. The *Wiimote* is not suited for performing circular sliding movements with the thumb due to the size and shape of the D-PAD. Furthermore, the disconnected buttons of the D-PAD make it difficult to perform the task. In contrast to the first user study, the D-PAD received the most negative feedback. However, on average it was rated higher in accuracy and responsiveness.

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