Original article

Evaluation of time-preciseness in low-cost Android tablets for psychophysical studies

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Key words: reaction time, Android tablet, time-preciseness
Received: 12 May 2017/Accepted: 23 June 2017

Abstract

Low-cost Android tablets are useful devices for psychophysical studies because of their familiarity to participants, various built-in sensors, and network connectivity. However, their time-preciseness is not fully examined. To address this issue, I performed simple, visual reaction-time measurements using three low-cost Android tablets. The reaction time was simultaneously measured by external sensors and internal application programing interfaces (APIs). In all tablets, the internally measured reaction times were longer than the externally measured reaction times by approximately 120 ms; however good linearity existed between internally-and externally-measured reaction times for a 700-ms period. The results suggest feasibility of Android tablets for complex tasks that require longer reaction times as well as time-uncritical psychophysical applications.

Introduction

Low-cost Android tablets are now commercially available. The lowest price of a 7 inch Android tablets was 5699 yen at Amazon.co.jp [1]. Tablets have many advantages for psychophysical studies, such as portability, familiarity to people in daily life, various built-in sensors (*e.g.,* touch panels, cameras, microphones, GPS, and accelerometers), audio outputs, and various wireless connections (*e.g.,* WiFi and Bluetooth). In addition, the Android operating system (OS) has an application programing interface (API) capable of sub-millisecond time measurement (System.nanoTime) [2, 3]. These properties might make the device useful for recording human's everyday responses outside laboratory rooms, or surveys using many devices at the same time. However, as a multitask OS with a complicate graphical user interface, the Android OS does not guarantee high time-preciseness [4] and, to the best of my knowledge, the accuracy and preciseness of low-cost Android tablets for human responses have not been empirically examined, while the response time is one of the most important properties in psychophysics. To address this issue, the author examined three low-cost Android tablets, focusing on the time accuracy and preciseness of touch responses.

Materials and Methods

Tablets and the visual response task

Three low-cost 7-inch Android tablets were used (Table 1). The visual stimulus was a 450 × 450-pixel white area, which also worked as a

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Table 1. Specifications of Android tablets used in the study.

Tablet No.	Maker	Model	LCD	LCD pixels	Android version	CPU model	CPU clock (GHz)
#1	GEANEE	ADP-722	7-inch TFT	1024 × 600	4.4	Quad-core Cortex A7	1.3
#2	HUAWEI	Mediapad 7 youth	7-inch TFT	1024 × 600	4.1	Dual-core Cortex A9	1.6
#3	YUNTAB	Q88	7-inch TFT	1024 × 600	4.4	Quad-core Cortex A7	1.5

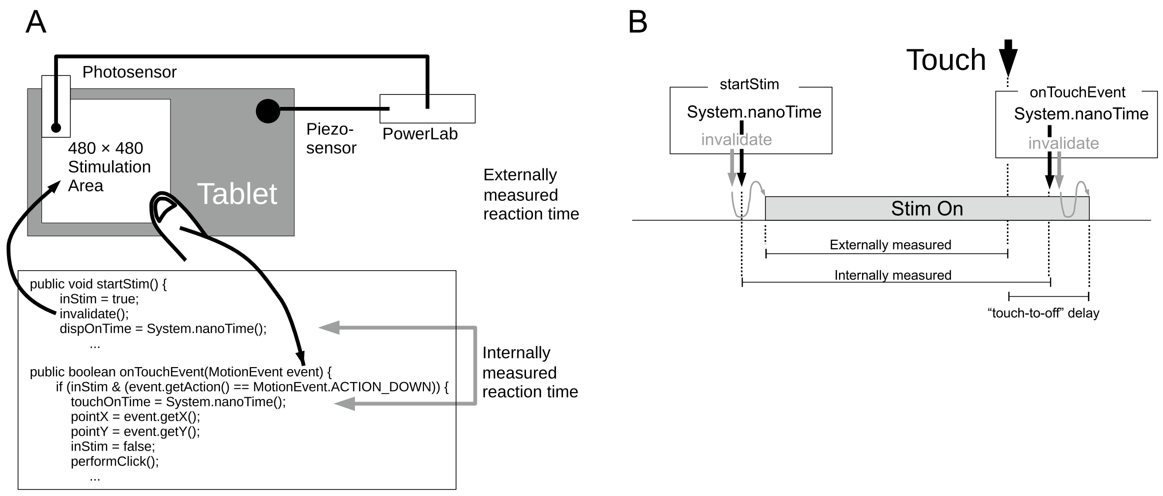

Figure 1.

A: Illustration of the experimental set-up and two fragments of the Java source code which include System.nanoTime API calls.

B: Timing chart of API calls for window invalidation, time measurement, and user touch. The stimulation area was redrawn after an invalidate API call by the windows subsystem of the Android tablet. When the tablet was touched at the stimulation area, the onTouchEvent event handler was called.

button (Figure 1A). The area turned black again right after the touch response. The inter-stimulus interval was pseudo-randomized between 1.0 and 2.0 s. All tasks were performed by the author. In most trials, after the stimulation area turned to white, the stimulation area was touched as fast as possible, while the response was intentionally delayed in some trials to evaluate the long-term accuracy of the internal time measurements. A session comprised 42 trials and commenced by pressing the start button. Sometimes the touch response in the first trials of a session could not be appropriately detected owing to the start button manipulation. The tablet was rebooted before each experiment to minimize the influence of daemon processes. In addition, a Windows tablet (W3-810fp, Acer, ROC) was used for comparison between Android and Windows OSs. The room luminance was 280 lx (SPI-6A, TOPCON, Japan).

Internal-and external measurements of visual reaction time

A reaction time measuring application was developed using Android Studio 2.3 for Mac [https://developer.android.com/studio/index.html]. Reaction times were internally measured via the sub-millisecond time measurement API of the Android OS (System. nanoTime). In each trial, the return values from System.nanoTime were recorded twice: just after invalidating the stimulation area and at the beginning of the OnTouch event handler attached to the area (Figure 1A). The reaction time was calculated by subtracting the former from the latter. At the same time, reaction time was recorded externally via a photosensor (NJL7502L, JRC, Japan; V_{CE}: 3 V, R_L: 3.3 kΩ) to detect the stimulation onset and a piezo-electric transducer (MP100 Pulse Transducer, ADInstruments, CO, USA) to detect the touch. The signals from both sensors were fed to an A/D converting unit (PowerLab 4/ST, ADInstruments, CO, USA) and recorded with a sampling frequency of 1 kHz. The display luminance was adjusted to approximately the midpoint value within the possible adjustment range, obtaining a natural looking target area. For each trial, stimulation onset was determined as the initial point at which the slope of luminance exceeded 1.8×10^4, 9.2×10^3, and 7.3×10^3 lx/s, for Tablet #1, #2, and #3, respectively. In a similar way, the end of stimulation was determined by a threshold of -9.2×10^3 lx/s for all tablets. The timing of touch was determined as the initial time when the output of the piezo-electric transducer deviated by 9×standard deviation (S.D.) from the mean of baseline value (calculated from the stimulation onset ± 100-ms period). An application to measure reaction time for the Windows tablet was developed using Lazarus/FreePascal [http://www.lazarus-ide.org] and run on Windows 10 (32-bit version).

Statistics

All statistical analyses were performed by GNU R [https://www.r-project.org]. Pooled data are represented in mean ± S.D., unless otherwise mentioned.

Results

Example time-courses of the luminance at the stimulation area and touch actions recorded with Tablet #1 are shown in Figure 2. The onset of visual stimulation was stably detected by the photosensor (Figure 2A). The time-courses of stimulation

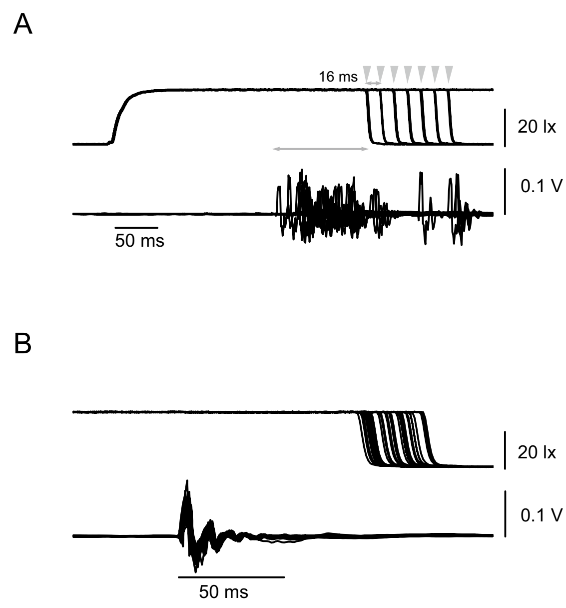

Figure 2.

A: Example time-courses for reaction time measurement. Upper traces: luminance of the stimulation area recorded in Tablet #1. Lower traces: touch responses recorded by the piezo-sensor. Data from 42 trials in a session were superimposed and aligned to the stimulus onset. Gray arrowheads: stimulation extinction time. Gray line with arrowheads at the center: "touch-to-off" delay in the trial with the shortest reaction time.

B: Data were similar to panel A. However, the traces were aligned to the reaction onset.

onset were strictly the same over all trials. All three tablets had a similar onset time-course (data not shown). In contrast, in the Windows tablet, the video frames were clearly observed and the time-courses of luminance varied from trial to trial (Figure 3). In Android tablets, the duration of the visual stimuli were not continuously distributed; however they had several distinct values (arrowheads in Figure 2A) separated from each other by approximately 16 ms, perhaps corresponding to the video frame refresh rate of the tablets. In addition, considerable delay was observed from touch response to disappearance of the visual stimulus ("touch-to-off" delay), which was approximately 80 to 130 ms and varied from trial to trial (Figure 2B). As shown in Figure 4A, the shortest externally measured reaction times were approximately 200 ms, which are comparable

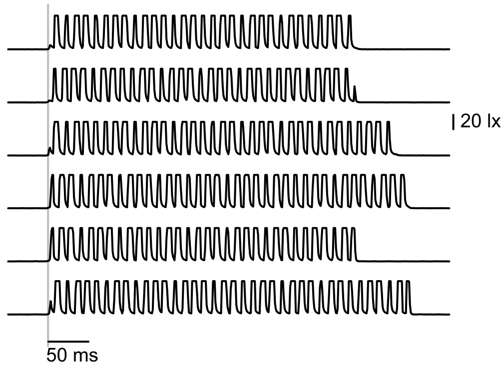

Figure 3. Luminance changes of the stimulation area in the Windows tablet at the stimulation onset. Data from the first six trials in a session are shown from top to bottom.

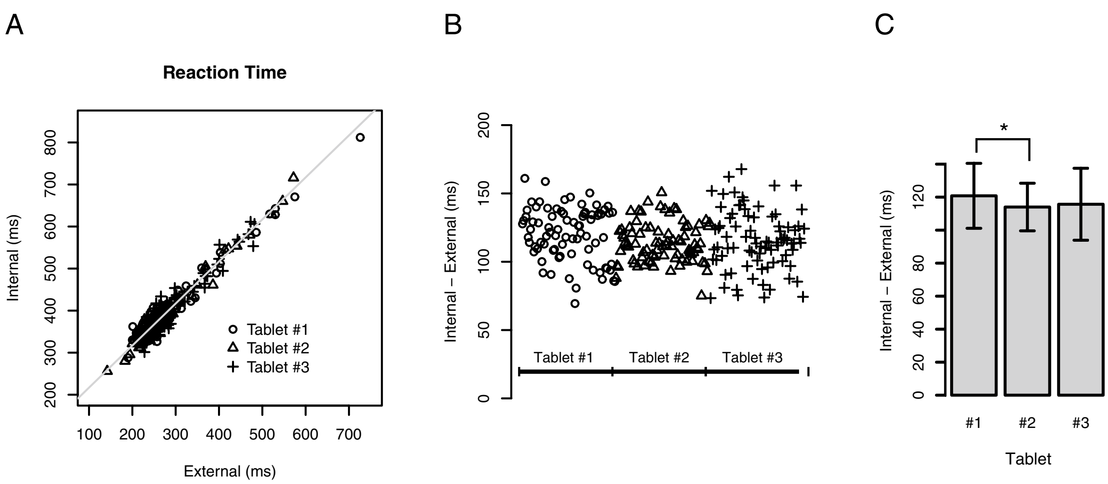

Figure 4. Difference between internally and externally measured reaction times.

A: Internally measured reaction times are plotted against externally measured reaction times. Each symbol represents a trial.

B: Differences between internally and externally measured reaction times are ordered left to right direction by the externally measured reaction time for each tablet.

C: The average overestimation time (internally measured reaction time minus externally measured reaction time) of each tablet (n = 84, 84, and 83 for Tablet #1, #2, and #3, respectively). Error bars represent S.D.s. *: $P < 0.05$, *post-hoc* *t*-test after oneway ANOVA, with Bonferroni correction.

to a previously reported simple visual reaction time [5, 6]. On the contrary, internally measured reaction times were overestimated in all three tablets. The linearity between the internally and externally measured reaction times was preserved for well over a 700-ms period (gray line). The overestimation was irrespective of the externally measured reaction time (Figure 4B). The average overestimation times were 120.8 ± 19.7, 114.0 ± 14.4, and 115.7 ± 21.8 ms, for Tablets #1, #2, and #3, respectively (Figure 4C).

One of the possible reasons for the overestimation of the internally measured reaction time is the response time of the touch panel to touch action. To avoid detection error in daily usage, the touch sensor or the window subsystem of the Android OS for touch detection should have integral or multiple-check mechanisms,

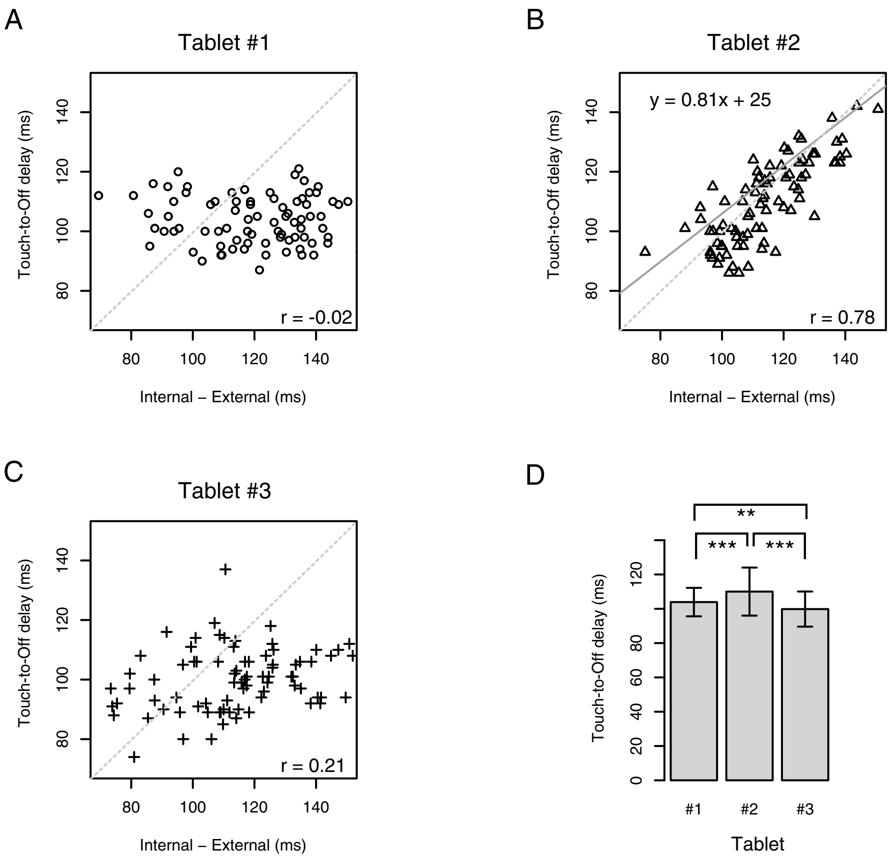

Figure 5.
A-C: “touch-to-off” delays are plotted against overestimation of the internally measured reaction time in (A) Tablet #1, (B) Tablet #2, and (C) Tablet #3. Each symbol represents a trial. The solid gray line in B is the regression line. If overestimation was only due to “touch-to-off” delay, all symbols must be on the dotted gray lines on each panel.
D: The average “touch-to-off” delay in each tablet. Error bars represent S.D.s. **: $P < 0.01$, ***: $P < 0.001$, *post-hoc* *t*-test after oneway-ANOVA, with Bonferroni correction.

which should cause a certain delay between the touch and dispatch of the onTouchEvent event handler. If the overestimation of the internally measured reaction time is attributable only to delay between the touch and the onTouchEvent call, "touch-to-off" delay must be shorter than the overestimation of internally measured reaction time, *i.e.*, the time between two System.nanoTime calls, in every trial, because System.nanoTime was called after invalidation of the stimulation area (making the stimulus turn on) and before the performClick API call (making the stimulus turn off, Figure 1B). To test this possibility, "touch-to-off" delays were plotted against the overestimation of the internally measured reaction times (Figure 5A-C). The "touch-to-off" delays were frequently longer than the delays between internally and externally measured reaction times (the left parts of the oblique gray lines). As shown in Figure 5D, average "touch-to-off" delays were significantly different among the three tablets (103.9 ± 8.3, 110.0 ± 14.0, and 99.8 ± 10.2 ms for Tablets #1, #2, and #3, respectively), and the order was in agreement with the central processing unit (CPU) specification of each tablet (#3 being the best, #2 being the worst). In addition, the correlations between "touch-to-off" delays and the overestimation of the internally measured reaction times were significant only for Tablet #2 (Figure 5B, Pearson's r = 0.78, $P < 2.2\times10^{-16}$) which had a dual-core CPU, but not significant for Tablets #1 and #3, which had a quad-core CPU. These results suggest that overestimation of the internally measured reaction time was not only due to the touch detection mechanisms of the Android OSs but also reflected that parallel processing of the video system and the main application thread were involved.

Discussion

Psychophysics has collaborated with computer sciences since the 1950s [8]. In this study, the latest low-cost Android tablets and their time preciseness were evaluated for psychophysical studies. In all three tablets, the shortest externally measured reaction times were comparable to a previously reported simple visual reaction time [5, 6]. This result indicates that the subject was required no special efforts to use these tablets in the psychophysical task. However, the internally measured reaction time was longer than the externally measured reaction time by approximately 120 ms (Figure 4). Compared to previously reported visual reaction time for single oddball task (approximately 200–400 ms [7]) as well as simple detection task, this overestimation might not be negligible. Even in these cases, however, if the same device is used, reaction times under different conditions could be compared with each other because the deviation of the internally measured reaction times was ± 20 ms, close to the interval between video frames (approximately 16 ms for a frame refresh rate of 60 Hz). The overestimation and its variance were irrespective of the externally measured reaction time (Figure 4B) and there was good linearity between the internally and externally measured reaction times. Therefore, the raw data should be directly applicable to complex tasks such as visual search or dual oddball tasks which require longer reaction times [9].

As shown in Figure 2A, luminance of the stimulation area increased in a similar manner throughout all trials. Such strict reproducibility was not observed in the Windows tablet (Figure 3), in which the stimulation area was redrawn asynchronously to the video frame timing. The same behavior was also observed in OS X (10.11.6, running on MacBook Pro, data not shown). The reproducibility of display luminance change in Android tablets may be preferable for psychophysical experiments with visual stimulation.

In addition to the time-preciseness indicated in this study, Android tablets has many useful features. Ease of programing is one of these features. An application package is compiled by freely distributed Android Studio and readily installed on an Android tablet via the universal serial bus cable without any restrictions. Low-cost, portable, and easy-to-program devices with many built-in sensors may be useful for many psychophysical studies not only for those without rich funding but also for field studies of human's everyday responses, or surveys using many devices at the same time.

Conflicts of interest

No potential conflicts of interest are disclosed.

References

1. Amazon.co.jp. Available from : https://www.amazon.co.jp/ (accessed March 14, 2017)
2. Reference for java. lang. Object. Available from : https://developer.android.com/reference/java/lang/System.html (accessed March 14, 2017)
3. Reference for java.lang Class System. Available from : https://docs.oracle.com/javase/1.5.0/docs/api/java/lang/System.html (accessed April 27, 2017)
4. Cláudio M, Luís N, Luís MP. Evaluating Android OS for embedded real-time Systems. International Workshop on Operating Systems Platforms for Embedded Real-Time Applications Workshop Proceedings. 2010; 62-69.
5. Lit A, Young RH, Shaffer M. Simple time reaction as a function of luminance for various wavelength. Percept Psychophys. 1971; 10(6): 397-399.
6. Murray MM, Foxe JJ, Higgins BA, Javitt DC, Schroeder CE. Visuo-spatial neural response interactions in early cortical processing during a simple reaction time task: A high-density electrical mapping study. Neuropsychologia. 2001; 39(8): 828-844.
7. Zou B, Utochkin IS, Liu Y, Wolfe JM. Binocularity and visual search-Revisited. Atten Percept Psychophys. 2017; 79: 473-483.
8. Bechtel W, Abrahamsen A, Graham G. Cognitive Science: History. In: Smelser NJ, Baltes PB (eds). International Encyclopedia of the Social & Behavioral Sciences. 1st ed. Elsevier Science Ltd. Amsterdam; 2001: 2154-2158.
9. Blundon EG, Rumak SP, Ward LM. Sequential search asymmetry: Behavioral and psychophysiological evidence from a dual oddball task. PLoS One. 2017; DOI:10.1371/journal. pone. 0173237.