Quality study of user activity using mobile device

Pan and touch & hold gestures

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ABSTRACT: The article presents the results of a quality study of the gestures performed by the users of a mobile device. The mobile device was a Nokia Lumia 800 smartphone. The results of the study concern the basic gestures of pan and touch & hold, and include the duration and precision of such gesture performance. The results include the division of participating users into groups by age and by daily smartphone use and non-daily smartphone use. A comparison of the determined characteristics between the groups is presented.

KEYWORDS: pan gestures, touch and hold gestures, gesture inputs with fingers, mobile device, gesture duration, gesture precision

1. Introduction

This paper continues the subject of [1] and shows the results of a quality study into the single-finger gesture performance of users operating a touchscreen mobile device. The mobile device used in the quality study was a Nokia Lumia 800 smartphone. The basic quality characteristics of the gestures studied here were: gesture duration, gesture precision (distance between finger application point and the centre of the touched object) and gesture error probability. The touch screen gestures used in the study were limited to one finger only. The study was carried out on a group of 60 people, aged 16-66 years.

2. Studied gestures

The quality study results for tap, double tap and flick gestures are presented in [1]. The focus of the study and the results presented here were the *pan* and *touch & hold* gestures. These gestures belong to a typical set of gestures performed by smartphone users with a touchscreen interface.

Panning is usually used for navigation between individual screens or menus at a user-controlled pace, or to relocate on-screen elements (in order to rearrange their order on the display). A pan is also known as a *swipe* or a *fling*. This gesture ends by lifting the finger or a stylus clear of the touch screen. Panning was modified in this study as follows: a finger was applied to the on-screen object and the object was dragged in a specific direction to another specific (target) object.

Touching & holding is usually used for displaying context menus or a subpage with options for the on-screen element being touched and held. This gesture is performed by touching an on-screen element and holding the finger there for a certain period of time. Unlike other touchscreen gestures, touching and holding is used less frequently. Just as in *tapping*, a touch and hold gesture ends by lifting the finger or stylus clear of the touch screen.

3. References

The paper [1] includes an overview of selected research available in the literature and focuses on the quality assessments of touch gestures performed by mobile device users.

The subject of quality studies for gesture performance by mobile device users is important for research into human-computer interface (HCI) interaction design. The need to consider the quality studies of user actions in mobile device HCI design engineering is highlighted in many research papers. Recent examples include [2], [3], [4]. As indicated in the reference literature, the results of the studies help HCI design engineers identify the best interaction performance for users with full perception and mobility capacities as well as users with challenged perception and/or mobility [2] or capable of one-hand operation only [3].

Proposals for four different touch screen display sizes for seniors, younger adults and children are detailed in [4] and stem from such studies of user interaction performance.

4. Study test conditions

4.1. Mobile device tested

As in [1], the mobile device used in the test was a Nokia Lumia 800 smartphone ("smartphone"). The basic specifications of the smartphone were: MS Windows Phone 7.5 Mango operating system, and Qualcomm MSM8255T 1.40 GHz single-core CPU. Display type: 3.7" capacitive multi-touch screen; AMOLED with ClearBlack, supported resolution — WVGA (480 × 800 px, 252 ppi ~54.7% screen-to-body ratio) [10], [11]. The capacitive touchscreen precluded any use of a stylus.

4.2. Study test application

The application specified in [1] was used to complete the study. Below is a summary of the test application.

The test application had a modular design (Fig. 1) [5]:

– *Mobile Application* module, launched on the smartphone's Windows Phone operating system;

– *Analysis Program* module, launched on an IBM PC with a Windows 7 operating system;

– *Server Program* module, a Web service launched on the IBM PC.

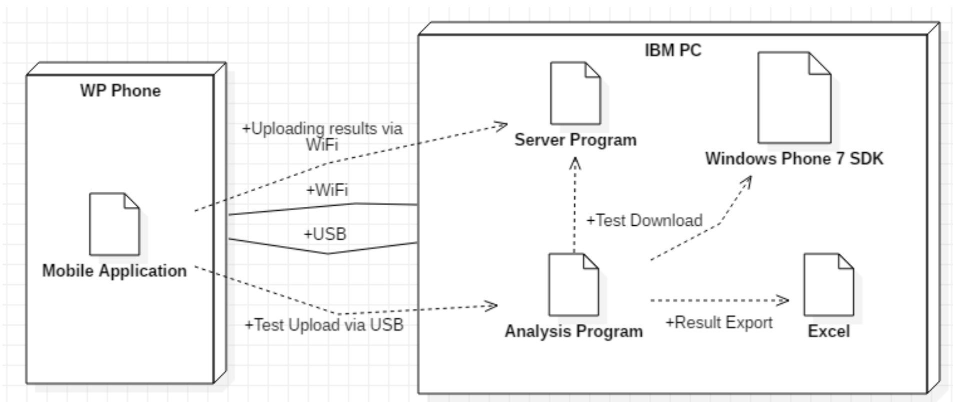

Fig. 1. Architecture of the test application [5]

Each smartphone user launched the *Mobile Application* module, answered a short questionnaire (Fig. 2a) and performed specific gestures, with a specific number of iterations of each gesture (Fig. 2b). Fig. 2c demonstrates an example of the smartphone screen with on-screen objects displayed before a gesture is performed.

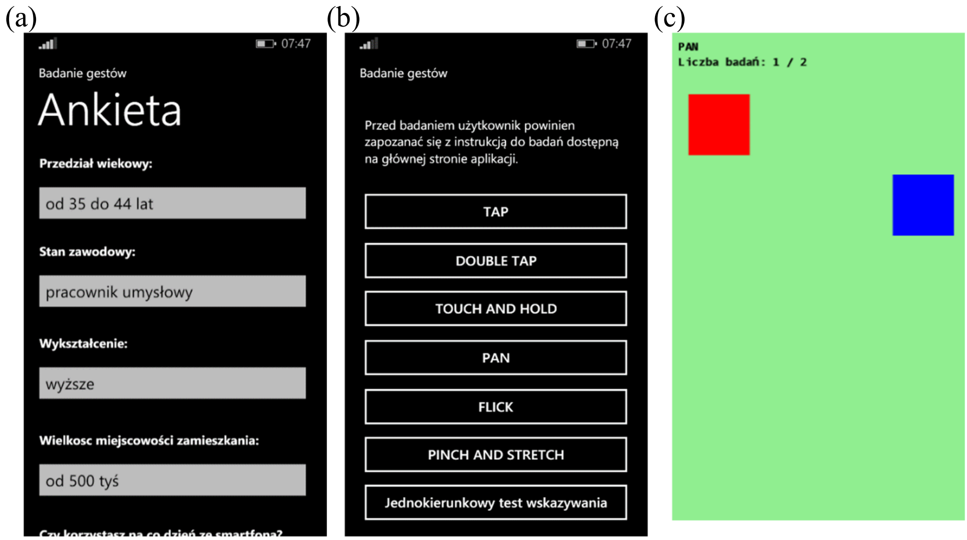

Fig. 2. Mobile Application: (a) questionnaire form; (b) measurement types; (c) smartphone screen during a single pan gesture [5]

The results were sent over a WiFi link from the *Mobile Application* module back to the *Analysis Program* module via the *Server Program* module Web service, or directly via a USB interface from the *Mobile Application* to the *Analysis Program*. The *Analysis Program* (Fig. 3) could present the overall results (for all tested smartphone users) and the results from individual tests (for single gestures or users).

Selected test results could be exported from the *Analysis Program* to an MS Excel spreadsheet file. In this quality study, the results were exported to an MS Excel spreadsheet file for further processing. The basic data exported to and available in the MS Excel spreadsheet included:

– touch gesture object hit or miss;

– finger to object distance at the touch time;

– gesture performance duration.

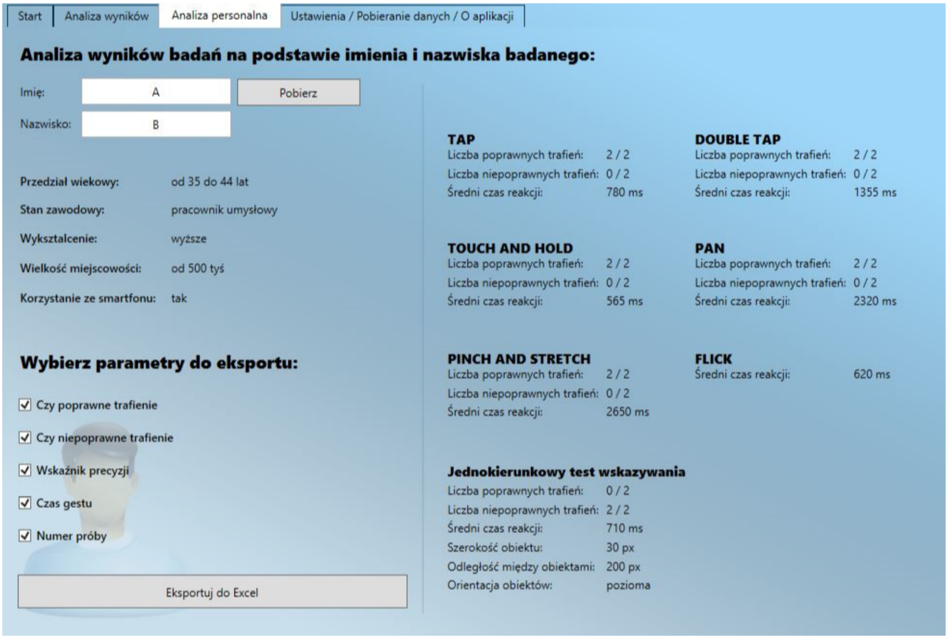

Fig. 3. Example of the display in the *Analysis Program* module [5]

4.3. Number of tested smartphone users and test conditions

The number of tested smartphone users and test conditions were identical to those specified in [1]. An abbreviated summary is shown below.

The number of tested smartphone users is shown in Table 1. The test group included 60 smartphone users aged between 16 and 66 years. The test group was dominated by teenagers and young and middle-age adults. Five different age groups were classified and designated from 1 to 5. The test group included 2 women.

Table 1. Number of tested smartphone users

Age group [years]	16-24	25-34	35-44	45-54	≥55	Total
Group no.	1	2	3	4	5	
Number of users	14	5	23	13	5	60

The smartphone users were mostly male, and included university-graduate office workers, a handful of secondary-level students and university students. The test group comprised people who were daily smartphones users and others who others were not daily smartphone users (Table 2). Each smartphone user repeated each gesture 30 times.

Table 2. Number of daily and non-daily smartphone users

Feature	Smartphone user	Non-smartphone user
Number of users	48	12

The tests were carried out in an indoor setting, between the hours of 08:00 and 16:00. Each user held the smartphone upright (in portrait orientation) in his or her left hand (there were no left-handed users in the test group). During the test, each smartphone user remained stationary, either sitting or standing (those standing did not walk during the test). Each next on-screen (target) interaction object was displayed directly after the performance of the previous gesture. No induction or 'rehearsal' test occurred with any of the smartphone users before the test.

The focus of the study and the results presented here was the pan and the touch & hold gestures.

The basic performance parameters determined with the test measurements included:

− Mean gesture performance duration;

− Mean gesture precision.

The calculations required for the quality study were evaluated statistically according to [6], [7], and [9], as appropriate for the test conditions. The direct calculations and charts were completed with the MATLAB software [8].

5. Pan gesture test results

The pan gesture procedure involved applying a finger to a specific on-screen object and then moving the object, with the finger held against the touch screen, in a specific direction towards a specific target object (a gesture type also known as 'drag and drop'). The gesture ended by lifting the finger clear from the touch screen. The object manipulated in the tests was a red square, 100 × 100 pixels in size (Fig. 4). The target object was a navy-blue square of the same size. The squares were displayed in random locations on the smartphone touch screen.

The values measured and recorded for each tested smartphone user (Fig. 5) were:

x_{s1}, y_{s1} – coordinates of the target object (Square 1) centre;
x_{s2}, y_{s2} – coordinates of the manipulated object (Square 2) centre at the time of gesture end;
t_a – time when the objects appeared on the touch screen;
t_b – gesture end time.

The condition of a correct pan gesture was:

$$ds_{12} \leq 20 \tag{1}$$

with: $ds_{12} = \sqrt{(x_{s1} - x_{s2})^2 + (y_{s1} - y_{s2})^2}$ – as shown in Fig. 5.

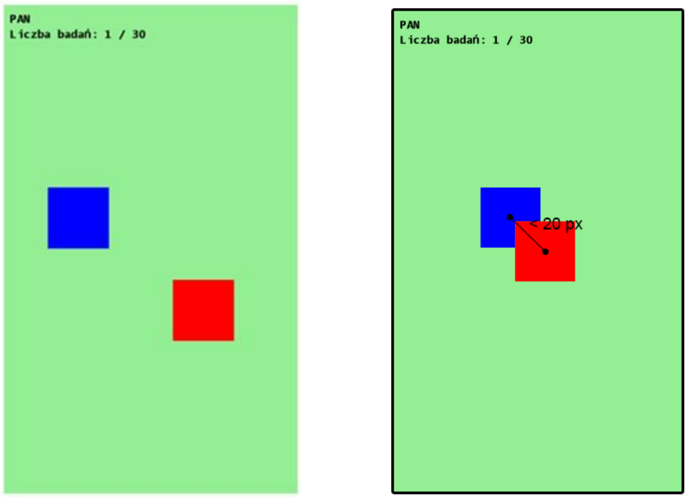

Fig. 4. Overview of the Nokia Lumia 800 screen during a pan gesture

The distance ds_{12} between the squares was determined by recording the centre coordinates of the squares (referred to here as "precision"):

Pan gesture duration t_1 by the user:

$$t_1 = t_b - t_a \ ;$$

with: t_a – time when the objects appeared;
t_b – gesture end time.

Based on the test measurements, the mean gesture precision, mean gesture duration and gesture error probabilities were determined for pan.

Mean gesture precision $\overline{ds}_{12}$:

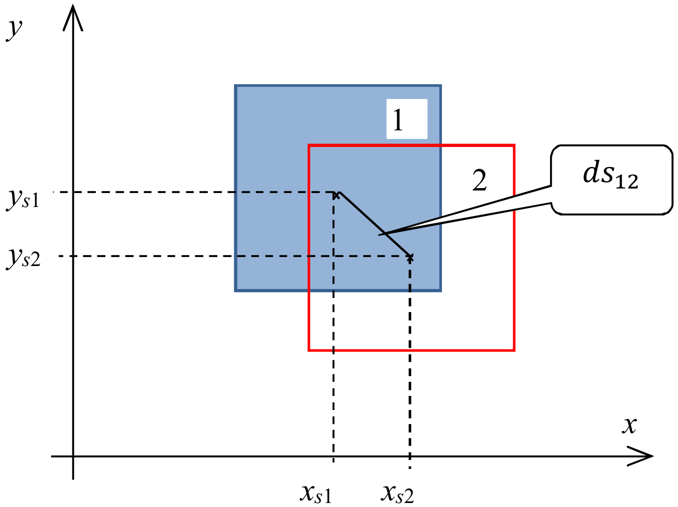

Fig. 5. Target object (Square 1) and manipulated object (Square 2) positions illustrated during a pan gesture, with: $(x_{s1}, y_{s1}), (x_{s2}, y_{s2})$ – Coordinates of the target object (Square 1) centre and manipulated object (Square 2) centre

$$\overline{ds_{12}} = \frac{1}{n}\sum_1^n ds_{12\,i}, \tag{2}$$

with: $ds_{12\,i}$ – gesture precision for measurement i;

n – number of gesture repetitions ($n = 30$).

Mean gesture duration $\bar{t}_1$:

$$\bar{t}_1 = \frac{1}{n}\sum_1^n t_{1\,i}\,, \tag{3}$$

with: $t_{1\,i}$ – gesture duration in for measurement i;

n – number of gesture repetitions ($n = 30$).

The pan gesture error probability was determined assuming correct gesture performance (see dependence (1)).

To enable appropriate comparisons, the mean pan gesture precision $\overline{ds}_{12}^{g}$ was determined for age group g, $g \in \{1, 2, 3, 4, 5\}$. The calculation results are shown in Table 3.

The mean gesture precision values indicated that many gestures performed by the smartphone users finished a considerable distance from the target.

Table 3. Mean pan gesture precision $\overline{ds}_{12}^{g}$ in specific age groups (for all gestures)

Age group [years]	16-24	25-34	35-44	45-54	≥55
Group g	1	2	3	4	5
Mean pan gesture precision $\overline{ds}_{12}^{g}$ [pix]	79.65	56.50	53.73	55.23	54.34
Precision standard deviation [pix]	133.8	106.6	116.7	107.3	101.8

This was confirmed by significant precision standard deviation values (see Table 3). The mean pan gesture precision, precision standard deviation and precision confidence intervals are shown in Fig. 6 for all gestures, classed by age group.

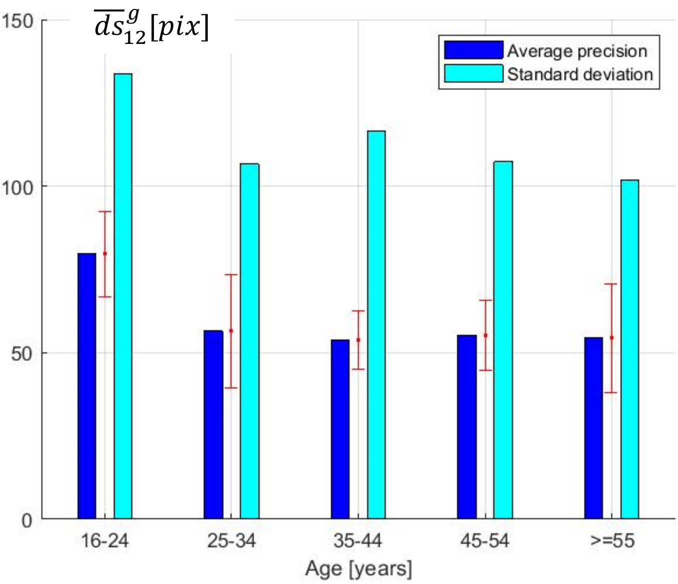

Fig. 6. Mean pan gesture precision $\overline{ds}_{12}^{g}$, precision standard deviation and precision confidence intervals for all gestures, classed by age group

A different approach was taken to analyse the measurement results. In this approach, only those gestures (i.e. measurements) were considered where the distance $ds_{12\,i}$ at the gesture end was not relatively large, which meant equal to or less than $a\sqrt{2}$, for example; here the manipulated object had minimum contact with the target object. Other gestures could be qualified as having considerable errors. Fig. 7 illustrates the location of a manipulated object and its target object in a situation conforming to this approach. Here a new condition for a correct gesture performance could be defined:

$$ds_{12} \leq a\sqrt{2} \tag{4}$$

with: ds_{12} – gesture precision;

a – square side length of the manipulated and target objects.

For this selection of gestures, the mean pan gesture precision $\overline{ds}_{12}^{g}$ and standard deviation were determined for each age group g, $g \in \{1, 2, 3, 4, 5\}$. The calculation results are shown in Table 4.

The mean pan gesture precision, precision standard deviation and precision confidence intervals are shown in Fig. 8 for the gestures which fulfilled condition (4).

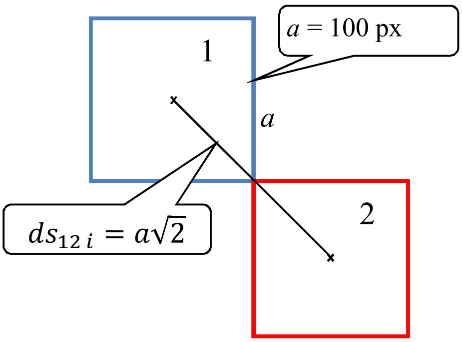

Fig. 7. Locations of the objects during a pan gesture, with the objects at the boundary of correct gesture performance allowing the results to be accepted

Table 4. Mean pan gesture precision $\overline{ds}_{12}^{g}$ in specific age groups (only the gestures which fulfilled condition (4) were considered)

Age group [years]	16-24	25-34	35-44	45-54	≥55
Group g	1	2	3	4	5
No. of measurements	330	128	604	341	134
Mean pan gesture precision $\overline{ds}_{12}^{g}$ [pix]	14.5	17.2	12.5	18.0	21.2
Pan gesture precision standard deviation [pix]	14.8	17.5	10.7	17.9	16.0

The results were compared between the age groups, and specifically, between age group 1 and the smartphone users from all other age groups.

The following hypotheses were formulated for mean gesture precision:

H0: mean precision values equal in age groups 1 and j ($\overline{ds}_{12}^{i} = \overline{ds}_{12}^{j}$);

H1: mean precision values not equal age groups 1 and j ($\overline{ds}_{12}^{i} \neq \overline{ds}_{12}^{j}$).

As the tests had many iterations, a typical mean value comparison test was used [6], [7]. The hypotheses were tested at significance level $\alpha = 0{,}05$. The comparison results are shown in Table 5.

For the completed tests, the mean pan gesture duration $\bar{t}_1^g$ was determined for age group g, $g \in \{1, 2, 3, 4, 5\}$. The gesture duration standard deviation and gesture duration confidence intervals were determined for the age group.

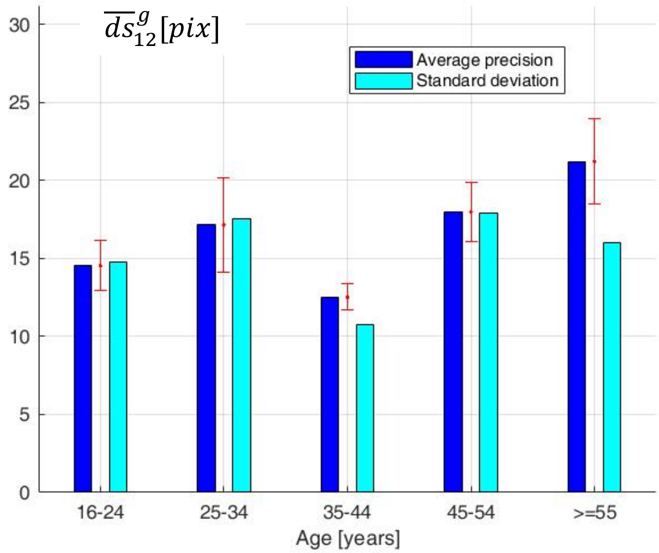

Fig. 8. Mean pan gesture precision $\overline{ds}_{12}^{g}$, precision standard deviation and precision confidence intervals for the gestures which fulfilled condition (4)

Table 5. Comparison results for the mean pan gesture precision between age group 1 and all other age groups (all gestures, and all gestures which fulfilled condition (4))

Groups in comparison	1-2	1-3	1-4	1-5
Decision on the result of a comparison of average precision (all gestures)	Discard H0	Discard H0	Discard H0	Discard H0
Decision on the result of a comparison of average precision (gestures which fulfilled condition (4))	Discarding H0 was not rational	Discard H0	Discard H0	Discard H0

Table 6 lists the calculation results for the mean gesture duration of all gestures performed, all gestured performed and fulfilling condition (4), and all correctly performed gestures (where condition (1) was fulfilled).

The mean pan gesture duration and its confidence intervals are shown in Fig. 9 for all gestures in the age groups, and in Fig. 10 for all correctly performed gestures (where condition (1) was fulfilled).

Table 6. Mean pan gesture duration $\bar{t}_1^g$ in specific age groups

Age group [years]	16-24	25-34	35-44	45-54	≥55
Group g	1	2	3	4	5
Mean pan gesture duration $\bar{t}_1^g$ (all gestures) [ms]	1838.1	1549.4	1989.0	2110.3	1743.2
Mean pan gesture duration $\bar{t}_1^g$ (gestures which fulfilled condition (4)) [ms]	1983.2	1655.8	2031.9	2178.4	1764.2
Mean pan gesture duration $\bar{t}_1^g$ (gestures which fulfilled condition (1)) [ms]	2214.7	1998.8	2102.6	2345.4	1841.0

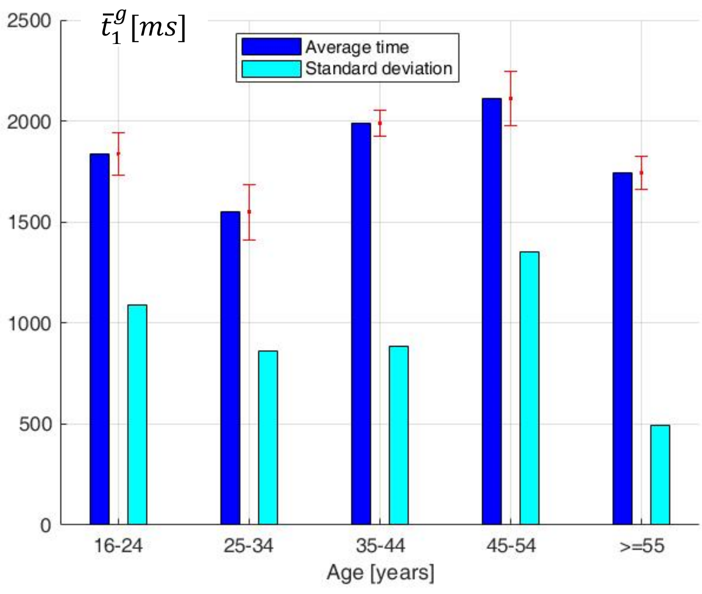

Fig. 9. Mean pan duration $\bar{t}_1^g$, duration standard deviation and duration confidence intervals for gestures in specific age groups (all gestures)

A comparison of the mean gesture duration values between the age groups (Table 6) revealed a marked increase in the duration of those correct gestures for which the condition of correct gesture performance (which means the gesture precision) became increasingly limiting. The results of the mean pan gesture duration were compared between age group 1 and the smartphone users from all other age groups.

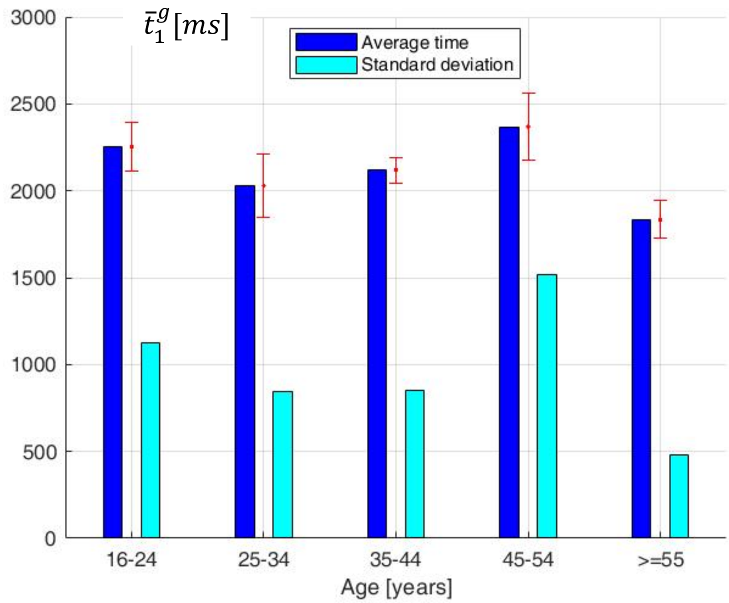

Fig. 10. Mean duration $\bar{t}_1^g$, duration standard deviation and duration confidence intervals for gestures in specific age groups (all correctly performed gestures which fulfilled condition (1))

The following hypotheses were formulated for the mean gesture duration:

H0: mean time values equal in age groups 1 and j ($\bar{t}_1^i = \bar{t}_1^j$);

H1: mean time values not equal in age groups 1 and j ($\bar{t}_1^i \neq \bar{t}_1^j$).

As the tests had many iterations, a typical mean value comparison test was used [6], [7]. The hypotheses were tested at significance level $\alpha = 0{,}05$. The results of the hypothesis verification are shown in Table 7.

Given condition (1) of a correct pan gesture, gesture error probability Pb_{pan} was determined for the age groups. The results are shown in Fig. 11.

The first condition of correct pan gesture (condition (1)) was a major limitation related to gesture precision; this gave the significant gesture error probability values. It was assumed that a correct gesture is any gesture where the manipulated object touches the target object (see Fig. 7). For this case, the condition of a correct gesture was expressed as (4).

With this correct gesture condition, the pan gesture error probability, Pb_{pan}, was determined for the age groups. The results are shown in Fig. 12.

Table 7. Comparison results for the mean pan gesture duration $\bar{t}_1^g$ between age group 1 and all other age groups

Groups in comparison	1-2	1-3	1-4	1-5
Decision on the result of the average time comparison (all gestures)	Discard H0	Discard H0	Discard H0	Discarding H0 was not rational
Decision on the result of the average time comparison (gestures which fulfilled condition (4))	Discard H0	Discarding H0 was not rational	Discard H0	Discard H0
Decision on the result of the average time comparison (gestures which fulfilled condition (1))	Discarding H0 was not rational	Discarding H0 was not rational	Discarding H0 was not rational	Discard H0

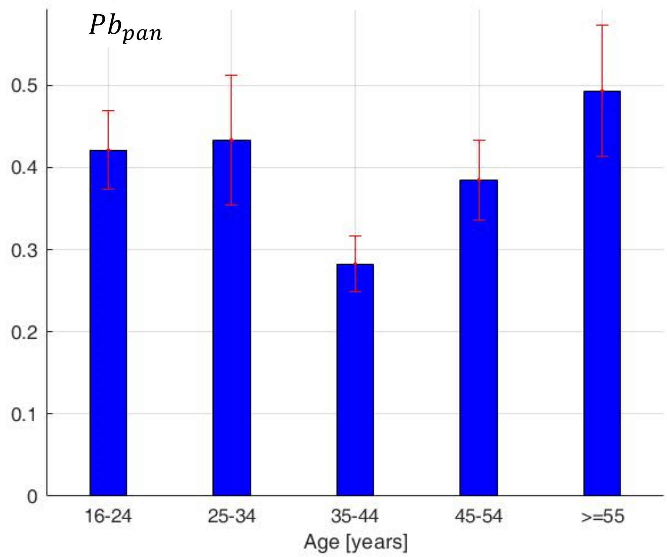

Fig. 11. Pan gesture error probability Pb_{pan} and confidence intervals in specific age groups (condition (1))

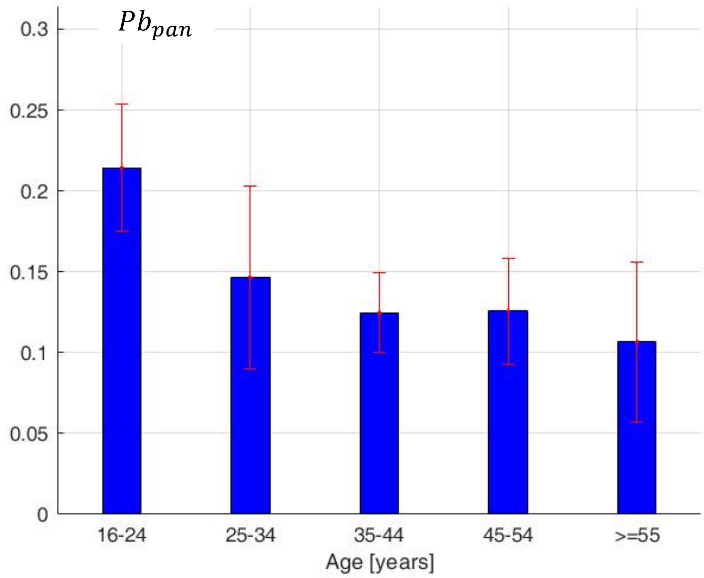

Fig. 12. Pan gesture error probability Pb_{pan} and confidence intervals in specific age groups (condition (4))

The following designations were used:

$\bar{d}^{u}_{12}$ – mean pan gesture precision of daily smartphone users;

$\bar{d}^{n}_{12}$ – mean pan gesture precision of non-daily smartphone users;

$\bar{t}^{u}_{1}$ – mean pan gesture duration of daily smartphone users;

$\bar{t}^{n}_{1}$ – mean pan gesture duration of non-daily smartphone users;

Pb^{u}_{pan} – pan gesture error probability for daily smartphone users;

Pb^{n}_{pan} – pan gesture error probability for non-daily smartphone users.

The results were used to determine the mean pan gesture precision, mean pan gesture duration and pan gesture error probability for the daily and non-daily smartphone users. Figs. 13 to 15 show the mean gesture precision results. Fig. 13 shows the results for all gestures tested. Fig. 14 shows the results for gestures which fulfilled condition (4). Fig. 15 shows the results for gestures which fulfilled condition (1).

Figs. 16 to 18 show the results for the mean pan gesture duration of daily and non-daily smartphone users. Fig. 16 shows the results for all gestures tested. Fig. 17 shows the results for gestures which fulfilled condition (4). Fig. 18 shows the results for gestures which fulfilled condition (1).

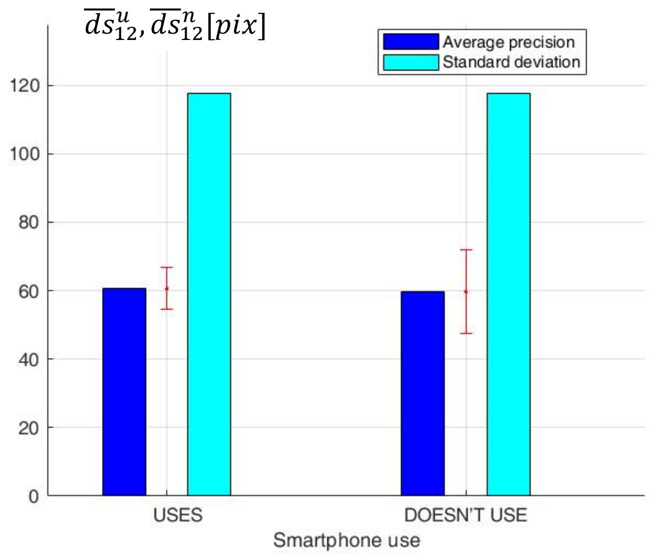

Fig. 13. Mean pan gesture precision, precision standard deviation and precision confidence intervals for smartphone users and non-users (all gestures)

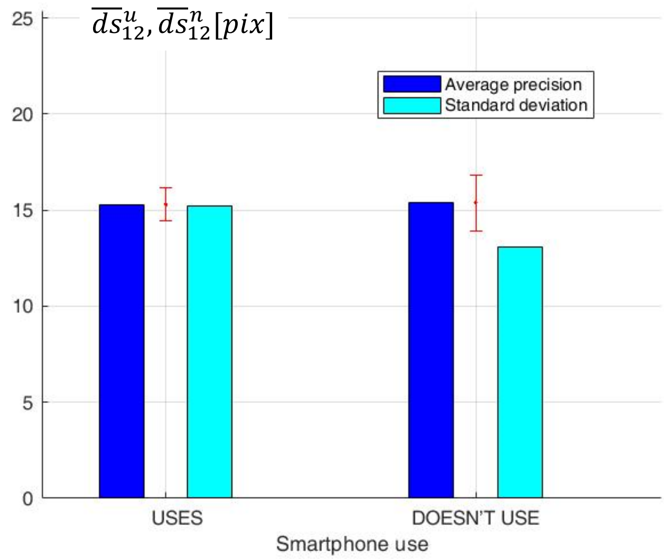

Fig. 14. Mean pan gesture precision, precision standard deviation and precision confidence intervals for smartphone users and non-users (gestures which fulfilled condition (4) only)

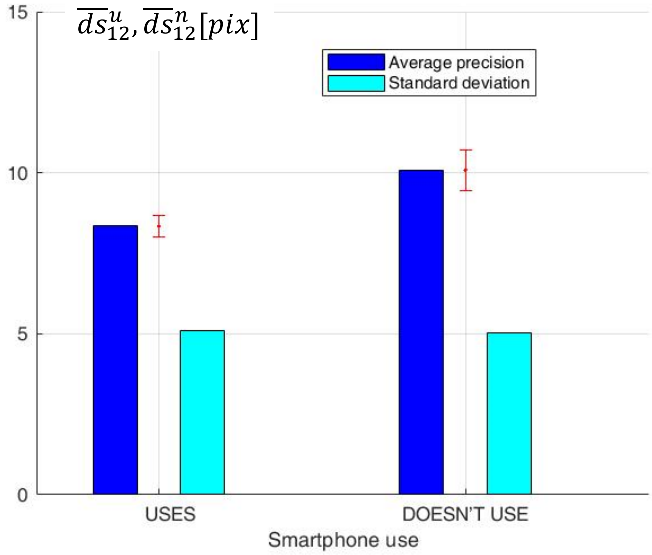

Fig. 15. Mean pan gesture precision, precision standard deviation and precision confidence intervals for smartphone users and non-users (gestures which fulfilled condition (1) only)

Figs. 19 and 20 show the results for the pan gesture error probability of daily and non-daily smartphone users. Fig. 19 shows the results for the gestures which fulfilled condition (4) and thus considered to be correct. Fig. 20 shows the results for the gestures which fulfilled condition (1) and thus considered to be correct.

It was also tested whether daily smartphone use was a factor of user activity quality. The following hypotheses were formulated:

H0: equal mean precision values (for daily and non-daily smartphone users) ($\overline{ds}_{12}^{u} = \overline{ds}_{12}^{n}$);

H1: non-equal mean precision values ($\overline{ds}_{12}^{u} \neq \overline{ds}_{12}^{n}$);

H0: equal mean gesture durations ($\overline{t}_{1}^{u} = \overline{t}_{1}^{n}$);

H1: non-equal mean gesture durations ($\overline{t}_{1}^{u} \neq \overline{t}_{1}^{n}$);

H0: equal gesture error probabilities ($Pb_{tap}^{u} = Pb_{tap}^{n}$);

H1: non-equal gesture error probabilities ($Pb_{tap}^{u} \neq Pb_{tap}^{n}$).

The hypotheses were tested at significance level $\alpha = 0{,}05$. The results of the hypothesis verification are shown in Table 8.

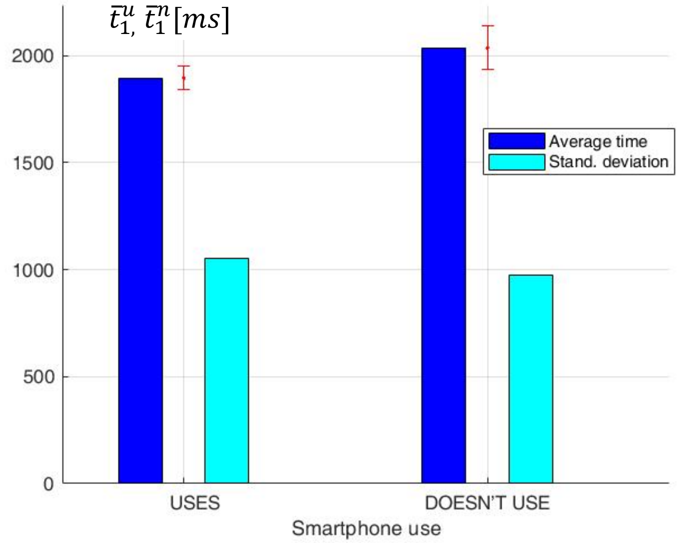

Fig. 16. Mean pan gesture duration, time standard deviation and time confidence intervals for smartphone users and non-users (all gestures)

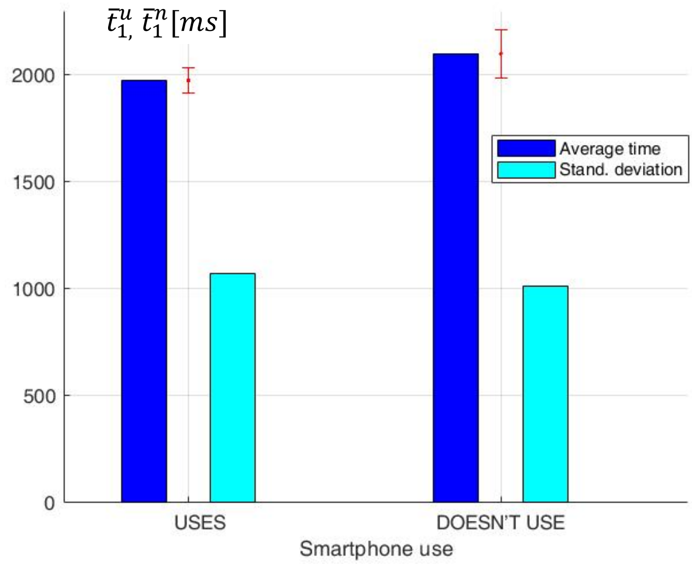

Fig. 17. Mean pan gesture duration, time standard deviation and time confidence intervals for smartphone users and non-users (gestures which fulfilled condition (4) only)

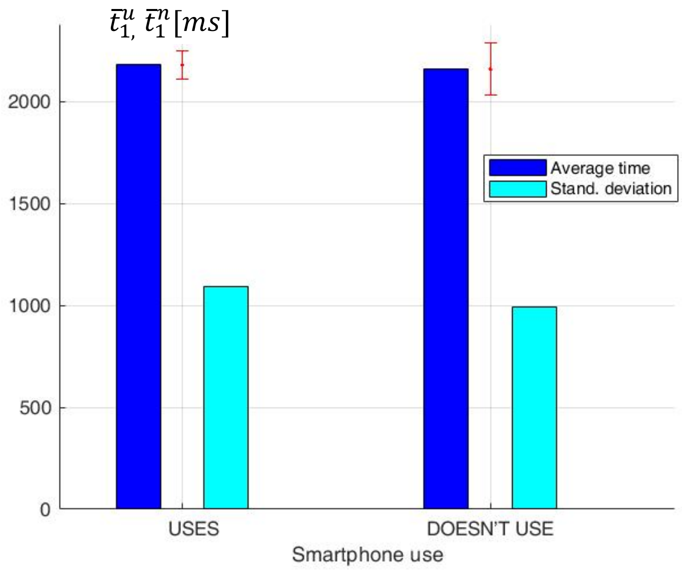

Fig. 18. Mean pan gesture duration, time standard deviation and time confidence intervals for smartphone users and non-users (gestures which fulfilled condition (1) only)

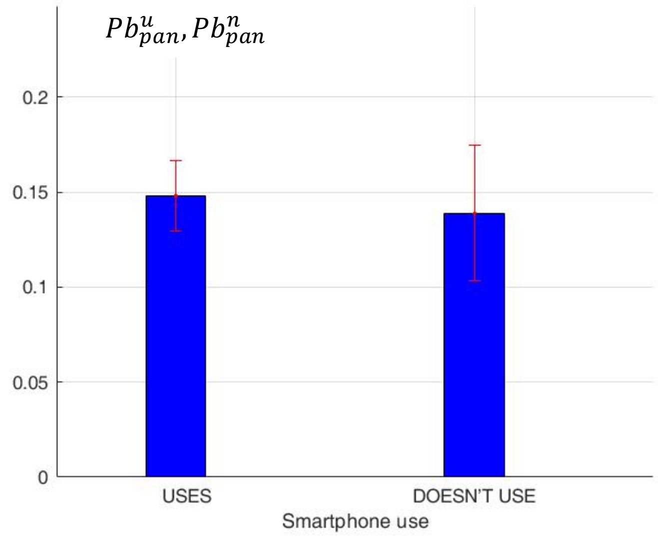

Fig. 19. Pan gesture error probability and its confidence intervals for smartphone users and non-users (the correct gestures fulfilled condition (4))

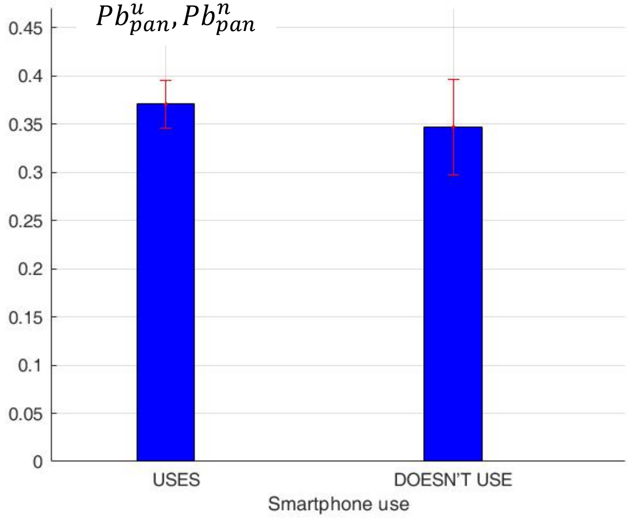

Fig. 20. Pan gesture error probability and its confidence intervals for smartphone users and non-users (the correct gestures fulfilled condition (1))

Table 8. Comparison results for the mean pan gesture duration and mean precision for smartphone users and non-users

Compared parameter	Mean gesture duration	Mean gesture precision
Decision on H0, all gestures	Discard H0	Discarding H0 was not rational
Decision on H0 (gestures which fulfilled condition (4) only)	Discarding H0 was not rational	Discarding H0 was not rational
Decision on H0 (gestures which fulfilled condition (1) only)	Discarding H0 was not rational	Discard H0

Considering the pan gesture error probability, it was not rational to discard H0, the hypothesis that the gesture error probability was equal for daily and non-daily smartphone users for both correct gesture conditions (condition (1) and (4)).

Comments and conclusions from the results

The results gave significant standard deviation values for mean pan gesture precision in each age group of the smartphone users (see Fig. 6). The standard deviation values for the mean pan gesture precision across the age groups were not that significant, however (see Fig. 9). For the mean pan gesture precision values across the age groups and for all tested gestures, many gestures performed by the tested smartphone users were found to end a considerable distance from the target object when compared to the mean pan gesture precision values for those gestures only which fulfilled condition (4) (see Table 4). By comparing the mean gesture precision values across the age groups in all tests, it was found necessary to discard H0, the hypothesis that the mean gesture precision was equal both in age group 1 and all other age groups. For the gestures which fulfilled condition (4), the comparison provided similar outcomes except for the comparison between age group 1 and age group 2 (see Table 5).

For the mean pan gesture duration $\bar{t}_1^g$ across the age groups, the mean gesture duration (of all gestures tested) and mean correct gesture duration values were compared (see values in Table 6). The calculations made as a part of this quality study found that it was necessary to discard H0, the hypothesis that the mean gesture durations were equal in the age group pairs 1-2, 1-3 and 1-4 for all gestures tested. The comparison between the mean gesture durations in age group 1 and age group 5 did not make it reasonable to discard the hypothesis that the mean gesture durations were equal. It was opposite for the gestures which fulfilled condition (1). It was not reasonable to discard H0, the hypothesis that the mean gesture durations were equal in the age group pairs 1-2, 1-3 and 1-4. It was necessary to discard H0 for the age group pair 1-5. A relatively low standard deviation of the mean gesture duration in age group 5 was characteristic (see Fig. 9 and 10).

The mean gesture durations became longer when they were considered only for the gestures which fulfilled condition (1) (see Table 6), since these gestures were qualified to be ‘correct’ (closer to the centre of the target object); naturally, dragging the manipulated object to a position closer to the target object centre took more time.

The pan gesture error probabilities shown in Fig. 12 and across the age groups were lower than the gesture error probabilities shown in Fig. 11. This is because the correct gesture condition (4) was less restrictive than condition (1).

The hypothesis that the pan gesture durations were equal between the daily and non-daily smartphone user groups for all tested gestures was discarded. The mean pan gesture precision did not make it reasonable to discard the hypothesis that this precision was equal between the daily and non-daily smartphone user groups for all tested gestures. In similar fashion, the mean pan gesture error probability did not make it reasonable to discard the hypothesis that this probability was equal between the daily and non-daily smartphone user groups for all tested gestures. Here, the results were identical to the results for the tap gesture (see [1]).

6. Touch & hold gesture test results

A touch & hold gesture was performed by touching an on-screen element and holding the finger there for a certain time. The object manipulated in the tests was a red square 100 × 100 pixels in size (Fig. 21). The square was displayed in random locations on the smartphone touch screen.

The values measured and recorded for each tested smartphone user (Fig. 22) were:

x_{so}, y_{so} – coordinates of the centre of the object (square);

x_p, y_p − coordinates where the user's finger touched the touch screen;

t_a − time when the object (square) appeared;

t_b – gesture end time.

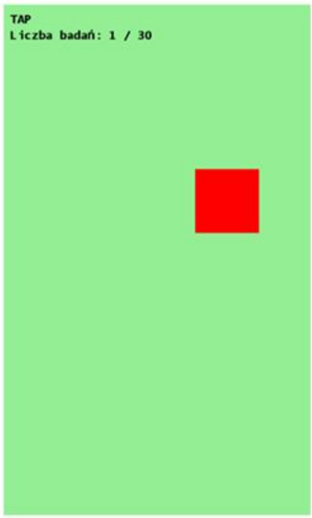

Fig. 21. Overview of the Nokia Lumia 800 screen during a touch & hold gesture

The condition of a correct touch & hold gesture were:

$$(x_{o1} \leq x_p \leq x_{o2}) \wedge (y_{o1} \leq y_p \leq y_{o2}) \tag{5}$$

with: $x_{o1}, x_{o2}, y_{o1}, y_{o2}$ – as shown in Fig. 13.

The following values were determined.

Distance d_{op} between the object and the finger (the precision):

$$d_{op} = \sqrt{(x_{so} - x_p)^2 + (y_{so} - y_p)^2} \,. \tag{6}$$

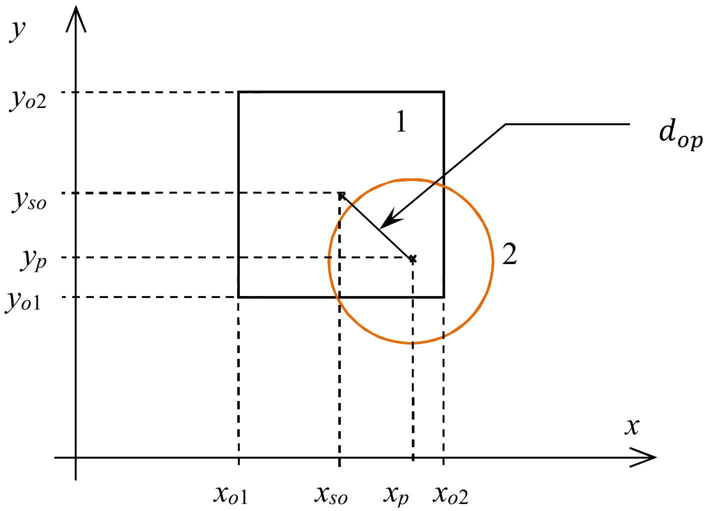

Fig. 22. Example of object 1 (square) and finger 2 locations on the screen during a touch & hold gesture, where:$(x_{o1}, y_{o1}), (x_{o2}, y_{o2})$ – coordinates of the object (square) 1 vertices;

The touch & hold gesture duration of the tested smartphone user:

$$t_1 = t_b - t_a \ .$$

Following the measurements, the mean gesture precision, mean gesture duration and gesture error probability were determined for touch & hold.

During each measurement of a touch & hold gesture, the time counter was stopped (in the test measurement tool) when the finger was removed from the touch screen. The hold time was 1 second. Hence the total gesture duration was the recorded gesture duration + 1 second in each instance. The results shown here account for the hold time.

To enable appropriate comparisons, the mean touch & hold gesture precision $\bar{d}_{op}^{g}$ was determined in age group g, $g \in \{1, 2, 3, 4, 5\}$. The calculation results are shown in Table 9.

The mean touch & hold gesture precision, precision standard deviation and precision confidence intervals are shown in Fig. 23, classed by age group.

In a similar fashion, the mean touch & hold gesture precision $\bar{t}_1^{g}$ was determined in age group g, $g \in \{1, 2, 3, 4, 5\}$. The gesture duration standard deviation and gesture duration confidence intervals were determined for the age group. Table 10 lists the calculation results for the mean gesture duration of all performed gestures and all correctly performed gestures (where condition (5) was fulfilled).

Table 9. Mean touch & hold gesture precision $\bar{d}_{op}^{g}$ in specific age groups g

Age group [years]	16-24	25-34	35-44	45-54	≥55
Group g	1	2	3	4	5
Mean touch & hold gesture precision $\bar{d}_{op}^{g}$ [pix]	18.80	15.61	15.89	13.85	16.86

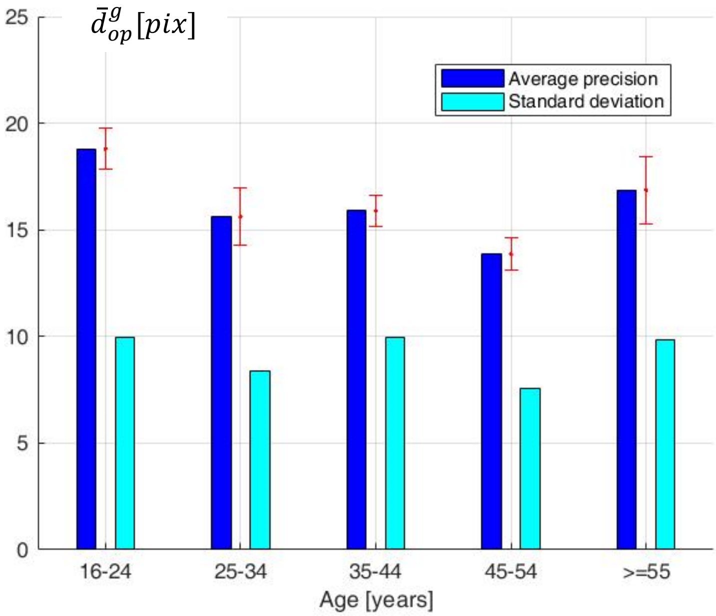

Fig. 23. Mean touch & hold gesture precision $\bar{d}_{op}^{g}$, precision standard deviation and precision confidence intervals in the age groups

Table 10. Mean touch & hold gesture duration $\bar{t}_{1}^{g}$ in specific age groups g

Age group [years]	16-24	25-34	35-44	45-54	≥55
Group g	1	2	3	4	5
Mean touch & hold gesture duration $\bar{t}_{1}^{g}$ (all gestures) [ms]	1735.9	1901.9	1772.94	1926.3	2152.1
Mean touch & hold gesture duration $\bar{t}_{1}^{g}$ (correct gestures) [ms]	1735.9	1901.9	1773.5	1926.3	2152.1

The mean touch & hold gesture duration, duration standard deviation and duration confidence intervals are shown in Fig. 24, classed by age group.

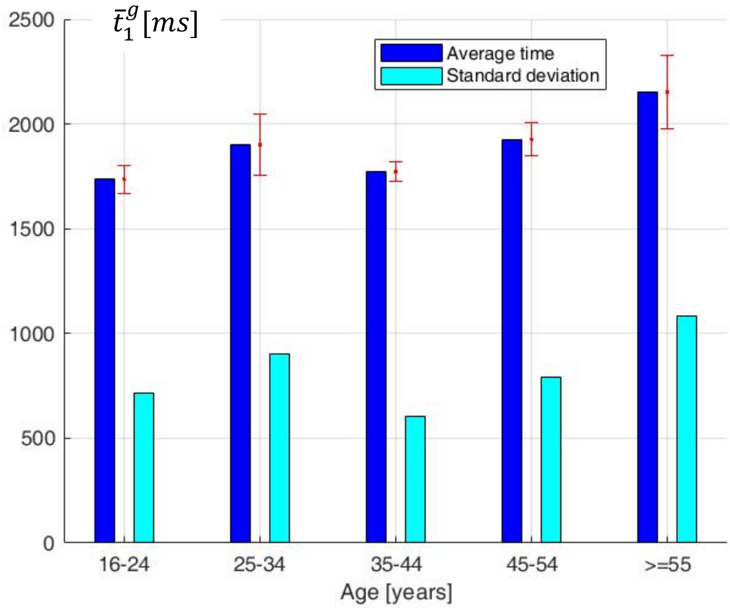

Fig. 24. Mean touch & hold gesture duration $\bar{t}_1^g$, gesture duration standard deviation and gesture duration confidence intervals in specific age groups (all gestures)

Given condition (5) of a correct touch & hold gesture, gesture error probability $Pb_{t\&h}^g$ was determined for the age groups. The results are shown in Fig. 25.

The results were compared between the age groups, and specifically, between age group 1 and those from all other age groups.

The following hypotheses were formulated for the mean gesture precision:

H0: mean precision values equal in age groups 1 and j ($\bar{d}_{op}^1 = \bar{d}_{op}^j$);

H1: mean precision values not equal in age groups 1 and j ($\bar{d}_{op}^1 \neq \bar{d}_{op}^j$).

In similar fashion the following hypotheses were formulated for the mean gesture duration:

H0: mean time values equal in age groups 1 and j ($\bar{t}_1^1 = \bar{t}_1^j$);

H1: mean time values not equal in age groups 1 and j ($\bar{t}_1^1 \neq \bar{t}_1^j$).

The hypotheses were tested at significance level $\alpha = 0{,}05$. The results of the hypothesis verification are shown in Table 11.

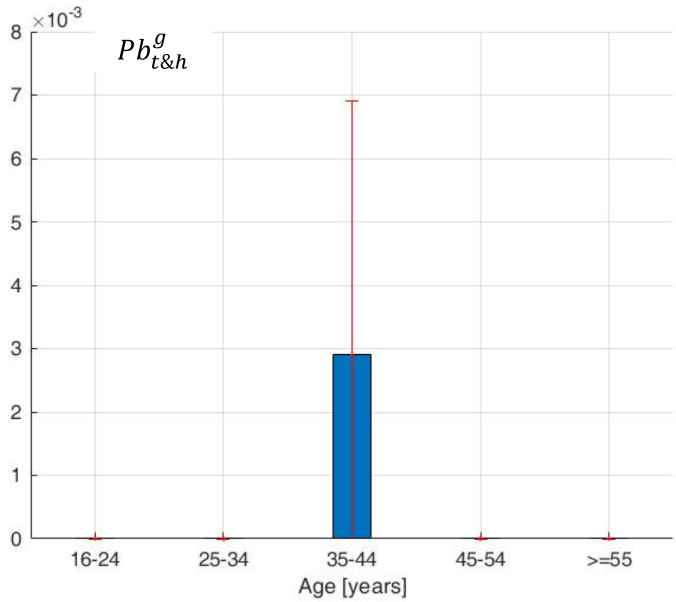

Fig. 25. Gesture error probability $Pb^{g}_{t\&h}$ and its confidence intervals in specific age groups

The following designations were used:

$\bar{d}^{u}_{op}$ – mean touch & hold gesture precision of daily smartphone users;

$\bar{d}^{n}_{op}$ – mean touch & hold gesture precision of non-daily smartphone users.

$\bar{t}^{u}_{1}$ – mean touch & hold gesture duration of daily smartphone users;

$\bar{t}^{n}_{1}$ – mean touch & hold gesture duration of non-daily smartphone users;

$Pb^{u}_{t\&h}$ – mean touch & hold gesture error probability of daily smartphone users;

$Pb^{n}_{t\&h}$ – mean touch & hold gesture error probability of non-daily smartphone users.

The results were used to determine the mean touch & hold gesture precision, mean touch & hold gesture duration and touch & hold gesture error probability of the daily and non-daily smartphone users. The results are shown in Figs. 26 to 28.

It was also tested whether daily smartphone use is a factor for user activity quality in users who perform touch & hold gestures. The following hypotheses were formulated:

H0: equal mean precision values (for daily and non-daily smartphone users) ($\bar{d}^{u}_{op} = \bar{d}^{n}_{op}$);

H1: non-equal mean precision values ($\bar{d}^{u}_{op} \neq \bar{d}^{n}_{op}$);

Table 11. Comparison results for the mean touch & hold gesture precision and time between age group 1 and all other age groups

Groups in comparison	1-2	1-3	1-4	1-5
Decision on comparison of average precision	Discard H0	Discard H0	Discard H0	Discard H0
Decision on comparison of average time	Discard H0	Discarding H0 was not rational	Discard H0	Discard H0

H0: equal mean time values ($\bar{t}_1^u = \bar{t}_1^n$);
H1: non-equal mean time values ($\bar{t}_1^u \neq \bar{t}_1^n$);
H0: equal gesture error probabilities ($Pb_{t\&h}^u = Pb_{t\&h}^n$);
H1: non-equal gesture error probabilities ($Pb_{t\&h}^u \neq Pb_{t\&h}^n$).

The hypotheses were tested at significance level $\alpha = 0{,}05$. The results of the hypothesis verification are shown in Table 12.

Table 12. Comparison results for the mean touch & hold gesture duration, gesture precision and gesture error probability for smartphone users and non-users

Compared parameter	Mean gesture duration	Mean gesture precision	Gesture error probability
Decision on H0	Discard H0	Discarding H0 was not rational	Discarding H0 was not rational

Comments and conclusions from the results

The results of this quality study revealed relatively moderate values of mean touch & hold gesture precision and its standard deviation in all age groups. When compared to the same values for the tap gesture (see Table 4 and Fig. 6 in [1]), the touch & hold values changed with age in a similar way and were lower, which meant that the touch & hold gestures were more precise than the tap gestures.

The high values of the mean touch & hold gesture durations were a result of the gesture itself, which required holding a finger on the target object (see Fig. 22).

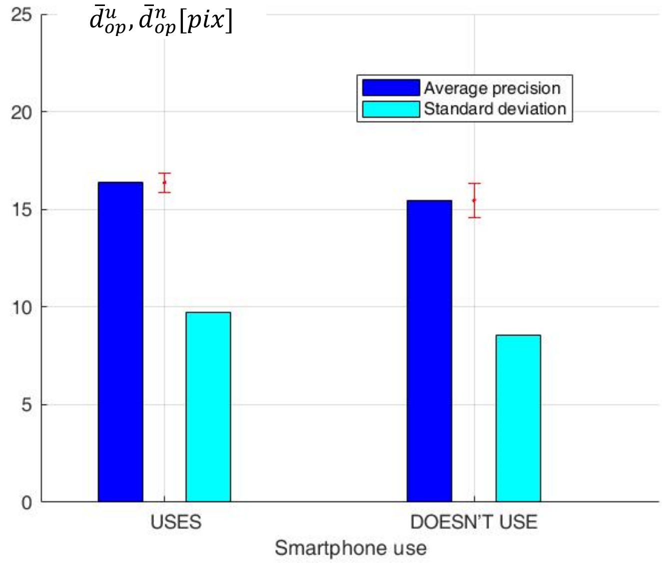

Fig. 26. Mean touch & hold gesture precision, precision standard deviation and precision confidence intervals for smartphone users and non-users

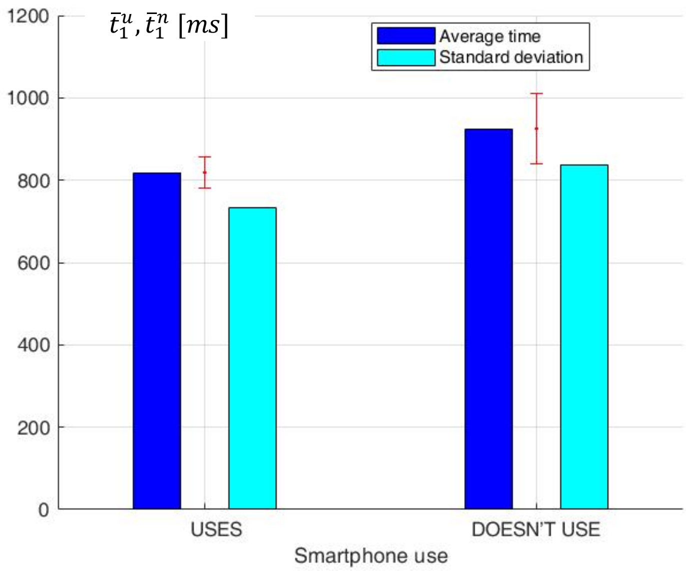

Fig. 27. Mean touch & hold gesture duration, duration standard deviation and duration confidence intervals for smartphone users and non-users

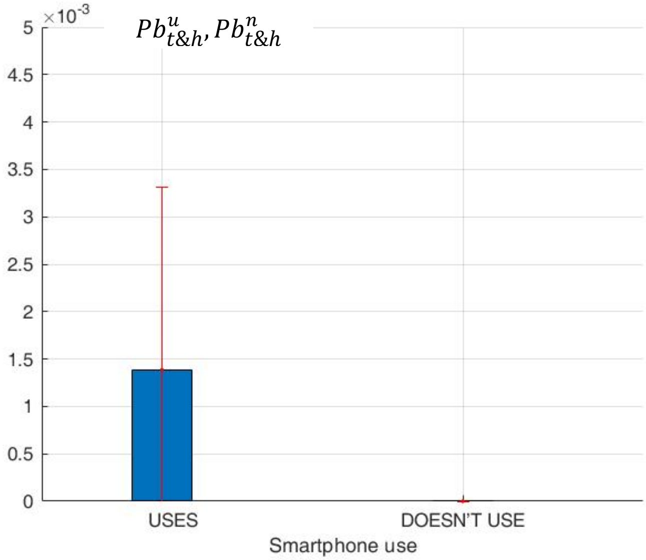

Fig. 28. Touch & hold gesture error probability and confidence intervals for smartphone users and non-users

The touch & hold gesture error probability was very low and only higher than zero for users in the 35 to 44 year old age group.

In all instances, the hypothesis that the mean gesture precision was equal between age group 1 and other age groups was discarded. A similar conclusion emerged from the tap gesture tests (see Table 6 [1]). In most instances, except for age group 3, the hypotheses discarded stated that the mean touch & hold gesture durations in age group 1 were equal to other age groups.

For both daily and non-daily smartphone users, the comparison results for the mean touch & hold gesture precision, gesture duration and gesture error probability were identical to those for the tap gesture (see [1]). The hypothesis that the mean gesture durations were equal was discarded. For the mean touch & hold gesture precision and gesture error probability, it was not found to be reasonable to reject the hypotheses that each of the two parameters were equal between the daily and non-daily smartphone users.

The gestures of tapping and touching & holding were not dissimilar in terms of performance precision; hence their mean gesture precision was compared between the age groups. The comparison results proved that it was necessary to discard H0, the hypothesis that the mean gesture precision performance was equal for touch & hold and tap in all age groups (age group 1 $p<0.00001$; age group 2 $p<0.01$; age group 3 $p<0.000001$; age group 4 $p<0.0000001$; age group 5 $p<0.01$).

7. Conclusion

This paper is the second part of a series discussing the results of a quality study of smartphone (and/or tablet) user activity related to touchscreen gestures for on-screen objects. The first paper of the series, [1], presented the quality study results for tap, double tap and flick gestures.

This paper focuses on the quality study results for pan and touch & hold. The latter gesture was modified to perform it by touching, dragging and dropping an object (a square) onto another object on a touch screen. The gestures were performed with fingers only, and no styli was used. The results include the mean gesture precision with its standard deviation and the mean gesture duration and its standard deviation by smartphone users in different age groups. The results were used to determine the mean gesture precision, mean gesture duration and gesture error probability in different age groups of daily and non-daily smartphone users.

For the gesture types investigated, a correct gesture condition was assumed to determine the gesture error probability in the age groups of the tested smartphone users.

The mean pan gesture precision values clearly indicate that a large number of gestures performed by the tested smartphone users finished a considerable distance from the target. By comparing the mean gesture precision values across the age groups in all tests, it was found necessary to discard H0, the hypothesis that the mean gesture precision was equal for age group 1 and all other age groups. The mean gesture durations were compared between the age groups. It was found necessary to discard H0, the hypothesis that the mean gesture durations were equal in the age group pairs 1-2, 1-3 and 1-4 for all gestures tested; the sole exception was the comparison in the age group pair 1-5. It was opposite for those gestures which fulfilled the condition of correct gesture performance.

The hypothesis that the pan gesture durations were equal between the daily and non-daily smartphone user groups for all tested gestures was discarded. The mean pan gesture precision did not make it reasonable to discard the hypothesis that this precision was equal between the daily and non-daily smartphone user groups.

The touch & hold gesture test results revealed that the mean gesture precision varied with age not unlike in the tap gesture (see [1]), but the values for touch & hold were lower, since the touch & hold gesture performance was more precise. The high values of the mean touch & hold gesture durations were a result of the gesture itself. Just as with the tap gesture in [1], the hypothesis was discarded that the mean gesture precision in age group 1 was equal to all other age groups. The hypotheses discarded stated that the mean touch & hold gesture durations for age group 1 were equal with other age groups.

The hypothesis that the pan gesture durations were equal between the daily and non-daily smartphone user groups for all tested gestures was discarded. For the mean touch & hold gesture precision and gesture error probability, it was not found to be reasonable to reject the hypotheses that each of the two parameters were equal between the daily and non-daily smartphone users.

Significant differences in gesture precision were found between touching & holding and tapping, despite a certain degree of similarity between the performance precision of the gestures.

The next article in the series will present the results of a qualitative study of user activity related to smartphones with other gestures than those discussed here.

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Badanie jakości działania użytkownika wykorzystującego urządzenie mobilne

Gesty pan oraz touch and hold

STRESZCZENIE: W artykule przedstawiono wyniki badań jakości wykonywania gestów przez użytkownika wykorzystującego urządzenie mobilne. Jako urządzenie mobilne wykorzystano smartfon Nokia Lumia 800. Wyniki badań dotyczą podstawowych gestów pan oraz touch and hold i obejmują czas wykonania gestu i precyzję wykonania gestu. Wyniki uwzględniają podział użytkowników na grupy wiekowe oraz grupy używające i nie używające smartfona na codzień. Przedstawiono porównanie wyznaczonych charakterystyk pomiędzy grupami.

SŁOWA KLUCZOWE: gesty pan, touch and hold, wprowadzanie gestów palcem, urządzenie mobilne, czas wykonania gestu, precyzja wykonania gestu

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