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Influence of Age and Palm Surface Area on Secondary Task Performance in a Driving Simulator

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ABSTRACT
Gesture control allows for reduced glance interaction compared to touchscreens when controlling secondary functions in cars. However, to date, there has been a lack of research investigating the influence of age and palm surface area (PSA) on performance during dual task applications, such as driving a car and using gestures with mid-air haptics feedback for controlling secondary functions. The following study investigates ways to introduce a characteristic feedback point on a virtual slider which differs from the adjacent points. This is either by changing the intensity or the distance to adjacent points. The time and the slider value set by the participant were saved. Participants gave ratings for each of the nine parameter sets by answering questions about the usability and the user experience questionnaire. The study consisted of two age groups: 30 younger participants with an average age of 31.0 years and 31 older participants with an average age of 63.0 years. Three of the older participants reported not feeling the mid-air haptics at all. Significant differences were found between the age groups in subjective and objective terms, and significant correlations for PSA and two subjective parameters. Further research will evaluate the findings in a more immersive static driving simulator.

KEYWORDS
human-machine-interaction; ultrasound; mid-air haptics; haptic slider; universal design; palm surface area.

1. INTRODUCTION

Touchscreens are the most widely used user interface in cars for secondary task execution, e.g. for entertainment functions [1]. As touchscreens are visual user interfaces, they can lead to high off-road glance times. A potential solution is the use of gesture control, which could lead to a reduction of off-road glance in comparison to touchscreens [2]. However, the current feedback for the execution of gestures is done primarily audio-visual. Harrington et al. [2] showed that mid-air haptics replacing audio-visual feedback for gesture control reduces off-road glance even more.

Mid-air haptics use modulated 40 kHz ultrasonic waves with modulation frequencies below 1,000 Hz in order to make them perceivable for the mechanoreceptors in the human hand [3]. This modulation can be done either by modulating the amplitude of one or several static focal points (amplitude modulation, AM), modulating the location of one or several focal points laterally (lateral modulation, LM) or by continuously moving one or several focal points on a specified path (spatiotemporal modulation, STM) [4]. The modulation frequency either defines the frequency with which the amplitude or lateral position is changed (AM, LM) [4] or the time how often the focal points move over the same location (STM) [5]. In this study, STM-modulation is used for modulation of the ultrasonic mid-air haptics.

There are four mechanoreceptors in the human hairless skin: Merkel cells, Ruffini Endings, Meissner and Pacinian corpuscles [6, 7]. Of those, either Pacinian corpuscles [8] or Meissner corpuscles [9] are the main mechanoreceptors for the reception of mid-air haptics, depending on the used modulation frequency. Meissner corpuscles are perceiving mainly to frequencies in the range of 1.5 to 50 Hz [6] and Pacinian corpuscles in the range of 40 to 800 Hz [10]. However, Pacinian corpuscles are most sensitive to frequencies between 250 Hz and 300 Hz [11]. For mid-air haptics, mostly modulation frequencies between 50 Hz and 300 Hz are used.

It should be possible for all, independent of age, to feel the mid-air haptics. Challenging in this regard is the reduction and change of mechanoreceptors [12-15] in the skin over age and the related decrease in tactile sensitivity [16-19]. So far, only little research has been conducted to investigate the influence of age on the reception of mid-air haptics. Rutten et al. [20] researched the recognition of different shapes of mid-air haptics singularly with 19-77 year old participants and found a strong correlation between increasing age and declining accurate recognition of shapes. However, in another publication of Rutten et al. [21] with the same participants investigating the discrimination ability of velocities and intensities, only a small relationship was found between age and discrimination accuracy. Fuchs et al. [22] investigated the influence of age on recognition and usability of a gesture-controlled virtual slider with mid-air haptics feedback with different snap distances and intensities in a dual task application with 63 participants aged 22 to 79 years. Fuchs et al. [22] showed that for elderly mid-air haptics with low intensities lead to a higher non-recognition rate, and that independent of age, secondary task performance for controlling a virtual slider improved with increasing snap distances and intensities. While driving, one of the 33 older participants did not feel the mid-air haptics in this implementation, independent of the used study parameters, and eight participants did not feel it without driving [22].

Dual task applications are, in general, challenging as dealing with the main task (e.g. driving) and secondary task (e.g. controlling a slider) leads, due to a limited mental capacity, to a decrease in task performance [23]. Schmid et al. [24] investigated a dual task application with a driving simulator and a touchscreen with electro-tactile feedback, but found no significant differences between participants aged 21 to 76 years split into two groups by age in terms of task fulfilment and subjective usability ratings. However, they found that an increasing intensity of the electro-tactile feedback or snap distance led to a higher adjustment accuracy for all participants [24]. Investigation of secondary task fulfilment of controlling a rotary control element with participants aged 55 to 78 years in a similar dual task application showed that symmetric torque and snap distances changes to signify a characteristic point led to higher task fulfilment rates than asymmetric changes [25].

So far, only Rutten et al. [20] investigated the influence of hand size, calculated as the sum of hand width and length, on the perception of mid-air haptics but did not find any correlation to the ability to discriminate velocities and intensities. Studies showed for the mechanoreceptors Merkel cells [26], which are mainly perceiving frequencies of 0.4 to 1.5 Hz [6], and Meissner corpuscles [27] that their density depends on finger sizes and is higher in smaller fingertips. When finger size is accounted for, no independent effect of sex was found by Peters et al. [26] for the spatial acuity of Merkel cells. It is unclear if that also applies to Meissner and Pacinian corpuscles, as Bensmaïa et al. [28] found that spatial acuity decreases with increasing vibration frequencies, which might mean that finger size has no influence at higher frequencies.

So far, there is a lack of research investigating the influence of age and hand size on the reception of mid-air haptics. In this study, the influence of age and palm surface area on secondary task performance of gesture control with mid-air haptic feedback is investigated in the dual task application of a driving simulator. In the methodology, the simulator and setup of the virtual slider with mid-air haptics and the procedure of the study are explained. This is followed by an overview of the results and an adjacent discussion of the inferential statistical investigations and findings. The paper is summarised in the conclusion, and an outlook for the next study in the research project is given.

2. METHODOLOGY

For this study, the Lane Change Test (LCT) software was used in combination with a standard computer screen, a simple gaming steering wheel and pedals [29]. The LCT is a standardised driving simulation developed for evaluation of human-machine interfaces in vehicles in a dual task application offering up to ten different track sections with lane changes in different orders [29]. Additionally, the LCT offers an analysis software to determine average speed and mean deviation from one lane after a certain lane change. This driving simulator consisted of different straight three-lane roads with lane change signs at equal distances and was used as the primary task. The participants were asked to change lanes quickly as soon as they could read the signs. The speed was limited via software to 60 km/h as defined in ISO 26022 [29], and participants were advised to maintain that speed the whole time. Depending on the study parameter, LCT track section, a bell tone was played at a different LCT sign position, indicating the start of the secondary task for the participants. From this point, the participants were asked to just stay in the lane, as studies in the past showed that this was already difficult to pursue next to the secondary task. Four different LCT track sections were used with a total of nine different LCT sign positions for the start of the secondary task (*Table 1*).

The secondary task consisted of a tactile indicator implemented as a virtual haptic slider in the software Unity, in combination with mid-air haptics produced by the Stratos Explore development kit of Ultraleap, with a leap motion controller for the gesture control [30]. The virtual haptic slider consisted of snap points distributed over the whole length of the slider. This produced a discrete feedback along the length of the 300 mm long slider. The feedback intensity of the mid-air haptics is given as a percentage, with 100 % corresponding to 1,124 Pa [30]. The snap distance is defined as the distance between the discrete mid-air haptic feedback points on this virtual slider in mm.

Table 1 – Study parameter (SP) variation

Study parameter (SP)	Intensity I_0 [%]	Intensity I_1 [%]	Snap dist. x_0 [mm]	Snap dist. x_1 [mm]	Snap dist. x_2 [mm]	Target slider value	LCT track section	LCT sign position
SP01	64	80	30	30	30	0.6	1	4
SP02	64	100	30	30	30	0.6	10	3
SP03	80	100	30	30	30	0.6	4	3
SP04	100	100	30	48	48	0.72	8	4
SP05	100	100	30	60	60	0.8	4	1
SP06	100	100	30	75	75	0.9	1	1
SP07	100	100	30	48	30	0.66	1	3
SP08	100	100	30	60	30	0.7	4	2
SP09	100	100	30	75	30	0.75	8	3

In this study, different ways to introduce a characteristic feedback point which differs from the adjacent points on a haptic slider (value 0 to 1) were investigated in nine study parameters (SP) combinations (*Table 1*). This was either done by changing the intensity, as in SP01 to SP03 (*Figure 1*) or the snap distance of the characteristic to adjacent points in SP04 to SP09 (*Figure 2*). The snap distance was changed symmetrically in SP04 to SP06 and asymmetrically in SP07 to SP09. Symmetrical means that snap distances before (x_1) and after (x_2) are the same, and asymmetric means that x_1 is larger than x_2 (*Figure 2*). The location of the characteristic point and the related location of the snap point to the right, which was the target slider value (TSV) to be set, was changing for every SP (*Table 1*). The intensity of the mid-air haptics and the snap distances were graded as defined in DIN 323-1 by the factor 1.25. The SPs were executed in a randomised order. The mid-air haptics were projected as a circle on the palm with a diameter of 16 mm and a modulation frequency of 80 Hz using spatiotemporal modulation.

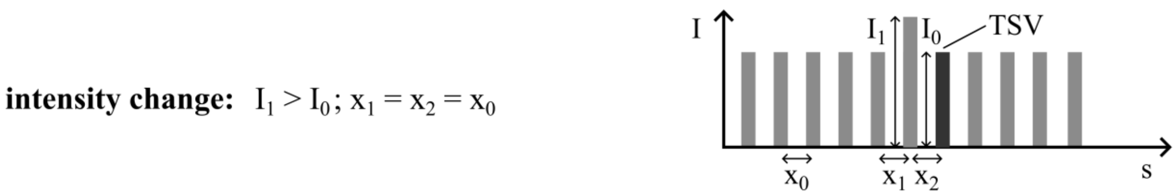

Figure 1 – Definition of intensities I_0 and I_1 and snap point distances x_0, x_1 and x_2 over the slider way s with the target slider value (TSV) for the study parameters SP01 to SP03 with intensity change based on [30]

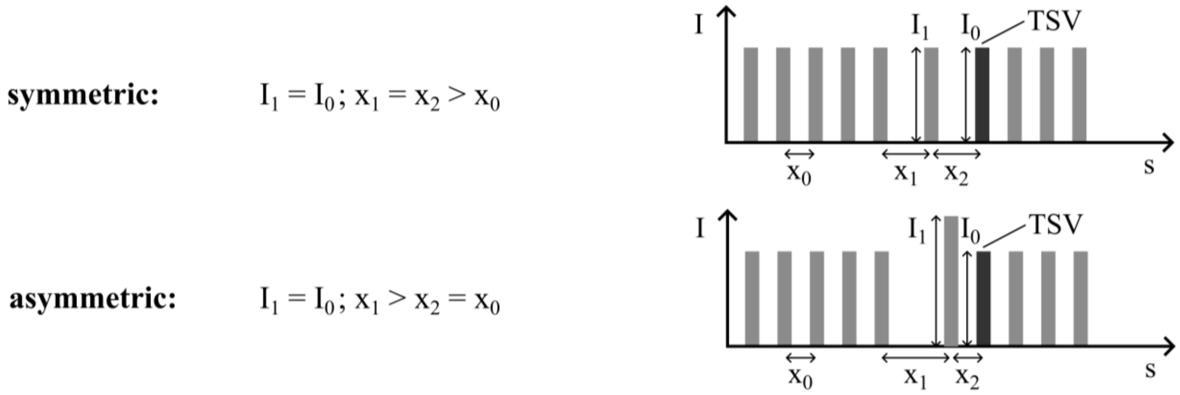

Figure 2 – Definition of intensities I_0 and I_1 and snap point distances x_0, x_1 and x_2 over the slider way s with the target slider value (TSV) for the study parameters SP04 to SP06 for symmetric and SP07 to SP09 for asymmetric implementation based on [30]

Additionally, a MediaPipe [31] based on Python software published by Kießling et. al. [32] with a standard HD-webcam was used for taking photos and calculating hand measurements, e.g. the index finger length. Palm surface area was mostly calculated for having a surface area relation to the whole body surface area for estimation of the size of the burned skin area. So far, only Rutten et al. [20] used the sum of hand length and hand width for assessing the influence of hand area size on the recognition abilities of mid-air haptics. In this study, the calculation of the palm surface area was based on the definition of a meta-analysis [33] (*Figure 3a*). Rhodes et. al. [33] defines the PSA as between the palmar crease of each digit and the interstyloid line, with the fingers and thumb close to the palm and in line with the forearm. As the edge recognition of MediaPipe requires the finger to be spread apart, the definition of palm surface area in this current study was altered in that regard. In this study, the calculation of the palm surface area was done by splitting the palm into triangles connecting hand landmark points found by MediaPipe. *Figure 3b* shows the annotated photo of a participant's right hand, which has been calibrated and evaluated as the landmarks. For each participant, eight to nine pictures (in one case six) of the right hand were evaluated in terms of index finger length (IL), width (IW), hand length (HL), palm width (PW) and palm surface area (PSA). The median of these assessed lengths and areas was calculated for each participant. A comparison of manually measured lengths and software calculated lengths showed agreement (median of the means of all standard errors of measured lengths: 6.2 %, and median of the means of all standard deviations of measured lengths: 8.3 %).

a) b)

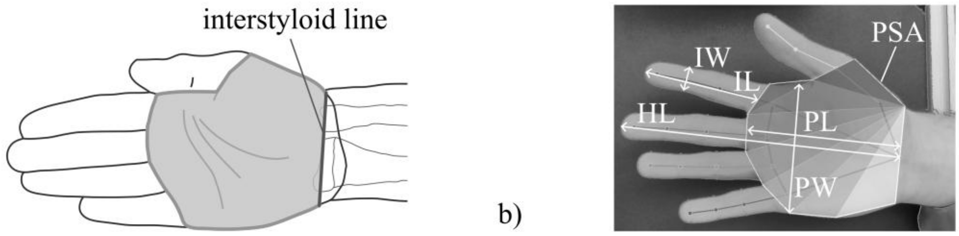

Figure 3 – (a) Definition of the palm surface area by [33] and (b) an annotated photo of a participant's hand with landmark points, approximated palm surface area and measured lengths (white lines)

2.1 Study participants

Requirements for participation were a car driver's licence and no feeling deficiency in the right fingers, hand and arm. 61 participants with an age of 21 to 79 years took part in the study (34 men, 27 women). The participants were separated into two groups by age. The definition of Pohlmann [34] of the "young old" starting with 55 years was used as the lower threshold of the older group, which means that participants 54 years old and younger are part of the younger group. The 30 younger participants (18 men, 12 women) had an average age of 31.0 years (SD = 8.6 years, range = 21-50 years). Three of the older participants did not feel the mid-air haptics at all and were removed from the study. Therefore, 28 older participants (13 men, 15 women) had an average age of 61.8 years (SD = 4.8 years, range = 55-73 years). 12.1 % of the younger and older participants were left-handed and 84.5 % right-handed. The study was 1 h 30 min long, and each participant received 50 € as an expense allowance.

2.2 Execution of the study

Participants were fully briefed about the experimental tasks and equipment prior to commencing the experimental tasks. Then demographic data of each participant were recorded, a pre-test for tactile sensitivity was executed, and hand measurements were taken. The measurements of index finger width, index finger length, palm width, as well as hand length of the right hand were taken manually and with the Python software (*Figure 4a*).

After the pre-tests, the participants were introduced to the main part of the study with the setup shown in *Figure 4b*. The location of the mid-air haptic unit in the centre console was previously defined with a Ramsis simulation as a compromise to be within the reach of the 5-percentile woman and 95-percentile man. An additional requirement for the location was a distance of 20 cm between the mid-air haptic unit and the participant's hand to keep the hand in the region of highest perceivable haptic feedback.

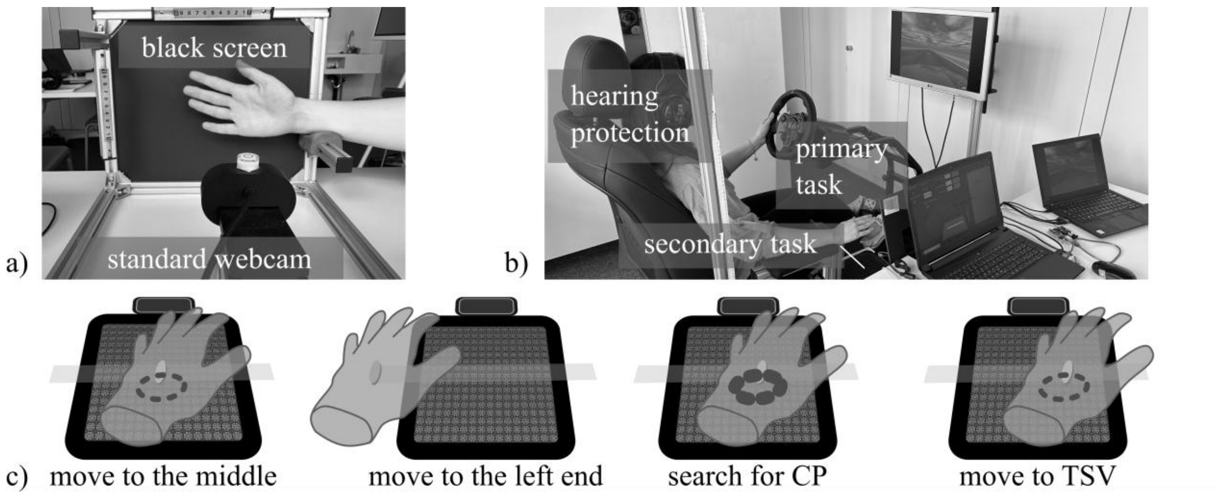

Figure 4 – Setup of the study: (a) configuration to photograph the right hand, (b) driving simulator and (c) secondary task

First, the primary task in the form of driving in the LCT simulator was explained (*Figure 4b*). The secondary task was then singularly introduced by letting the participants feel the mid-air haptics and explaining the way the virtual slider works. The participants were supposed to always move the virtual slider to the snap point right of the characteristic point. Next, the participants were shown how the primary and secondary tasks were combined with the study parameter SP05. The participants were instructed to drive in the simulator with hearing protection, with both hands on the steering wheel and make the lane changes until the bell rings. The bell sound indicated that the following lane change would be the last one, and the participants were supposed to stay in this lane until they finished with the secondary task. After the execution of this last lane change, the right hand was moved over 20 cm above the mid-air haptic user interface by laying the arm on the armrest. The participants moved their right hand first above the middle of the mid-air haptic unit to be recognised by the leap motion controller for the gesture control and feel the first haptic feedback points (*Figure 4c*). Then, participants moved to the left end of the virtual slider and searched from the left to the right end of the virtual slider for the characteristic point (CP). After recognising this one, the participants moved one more snap point to the right to set the slider to the target slider value (TSV) by holding their hands still for at least three seconds. When the participants were finished, they brought the vehicle to a halt and the trial was finished. While the secondary task executed the lateral mean deviation, from the ideal driving line in the LCT, the LCT mean speed, the setting time and the set slider value were automatically recorded. The setting time was also measured manually with a stopwatch. After each trial, the participants rated the usability of the gesture control with mid-air haptics in terms of effectiveness, efficiency and satisfaction in six questions on a 7-stage Likert scale and filled in the short user experience questionnaire in German (UEQ-S) [35].

3. RESULTS

The bar graphs for non-recognition rate and secondary task fulfilment are shown in *Figure 5,* and the boxplots for setting time, LCT mean deviation, LCT mean speed, precision, learnability and mental demand are shown together with the line graph of the UEQ-S in *Figure 6*. All younger participants felt every SP (*Figure 5*). 14.3 % of the older participants did not recognise SP01 and SP02, 10.7% SP03, 7.1% SP04, SP05 and SP07 to SP09, and 3.6% SP06. Task fulfilment of both groups was the highest for the symmetric characteristic points with 37.9% (SP04) to 51.9% (SP06) for the younger participants and with 19.3% (SP04) to 33.3% (SP06) for the older participants. The asymmetric characteristic points SP07 and SP09 had with 14.3% and 28.6% for the younger participants and with 19.2% and 15.4% still higher task fulfilment rates than the intensity characteristic points SP01 and SP03 with 7.1% and 10.7% for the younger participants and 12.5% and 12.0% for the older participants. Only for SP03 and SP07, the task fulfilment rate was higher for the older than the younger participants. The highest rate of task fulfilment for both groups was achieved for SP06 with 51.9% by the younger and 33.3% by the older participants. Setting time varied greatly, independent of the test characteristics for both older participants from 1 s (SP08) up to 130 s (SP06) and younger participants from 3 s (SP04) up to 125 s (SP01) (*Figure 6*). The lowest median setting time was achieved with 11 s for SP06 by the younger and with 11.5 s for SP09 by the older participants. Only for SP05 and SP06 was the median setting time of the younger with 13 s (SP05) and 11 s (SP06) lower than the median setting time of the older participants, with 15 s (SP05) and 12 s (SP06).

The median of the LCT mean deviation was for each SP for the younger with a range of 0.7 m (SP02) to 12.8 m (SP01) lower than for the older participants with 10.9 m (SP08) to 22.4 m (SP04). The median of the LCT mean deviation of the younger participants was for SP01 with 12.8 m, the highest and by far higher than the mean values (< 0.9 m) for all other SP. The median of the LCT mean deviation of the older participants was for SP06 with 20.4 m, the highest and SP09 with 13.6 m, the lowest. The average LCT mean speed was for each SP for the younger participants, with a range of 52.9 km/h (SP02) to 59.2 km/h (SP08), higher than the older participants, with 49.8 km/h (SP01) to 53.5 km/h (SP07). An increasing symmetric snap distance led to a lower average and greater range of LCT mean speed for the older participants, as seen in SP04 to SP06, with the lowest average LCT mean speed for SP06 with 53.2 km/h. In general, there were a few outliers for both groups in terms of low average LCT mean speeds, which were as low as 35.5 km/h (SP01, younger).

The median precision was rated lowest for SP01 by both groups, with -1.0 for the younger and 0.0 for the older participants (*Figure 6*). SP05, SP06 and SP08 had 1.5 the highest median precision rating by the younger and SP03-SP05 and SP07-SP09 with 1.0 by the older participants. The median learnability was rated by the younger participants for SP05 and SP06 and by the older participants for SP05, with 2.0 being the highest. The lowest median learnability rating was given by the younger participants for SP01 and by the older participants for SP06, with 0.0. The median mental demand ratings were for both groups over all SP between 3 (equals moderate) and 4 (equals fairly strong). In general, older participants rated the mental demand higher than younger participants.

The evaluation of the UEQ-S in *Figure 6* shows that the pragmatic quality was, for all SP, lower than the hedonic quality. The hedonic quality was rated by both groups for all SP between 1.37 (SP04, older) and 1.75 (SP05, younger), which equals a good to excellent rating based on the UEQ Benchmark. The pragmatic quality was rated between -0.68 (SP01, younger) and 0.82 (SP05, younger), which equals a bad to below average rating based on the UEQ Benchmark.

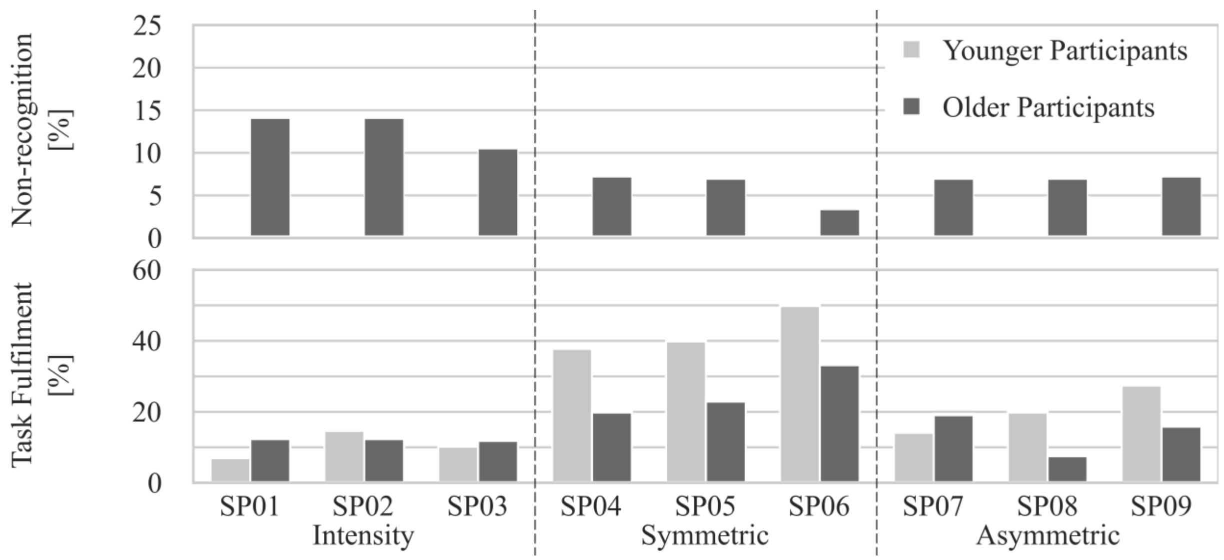

Figure 5 – Non-recognition rate and task fulfilment of the secondary task of the study with younger participants in light and older participants in dark colour

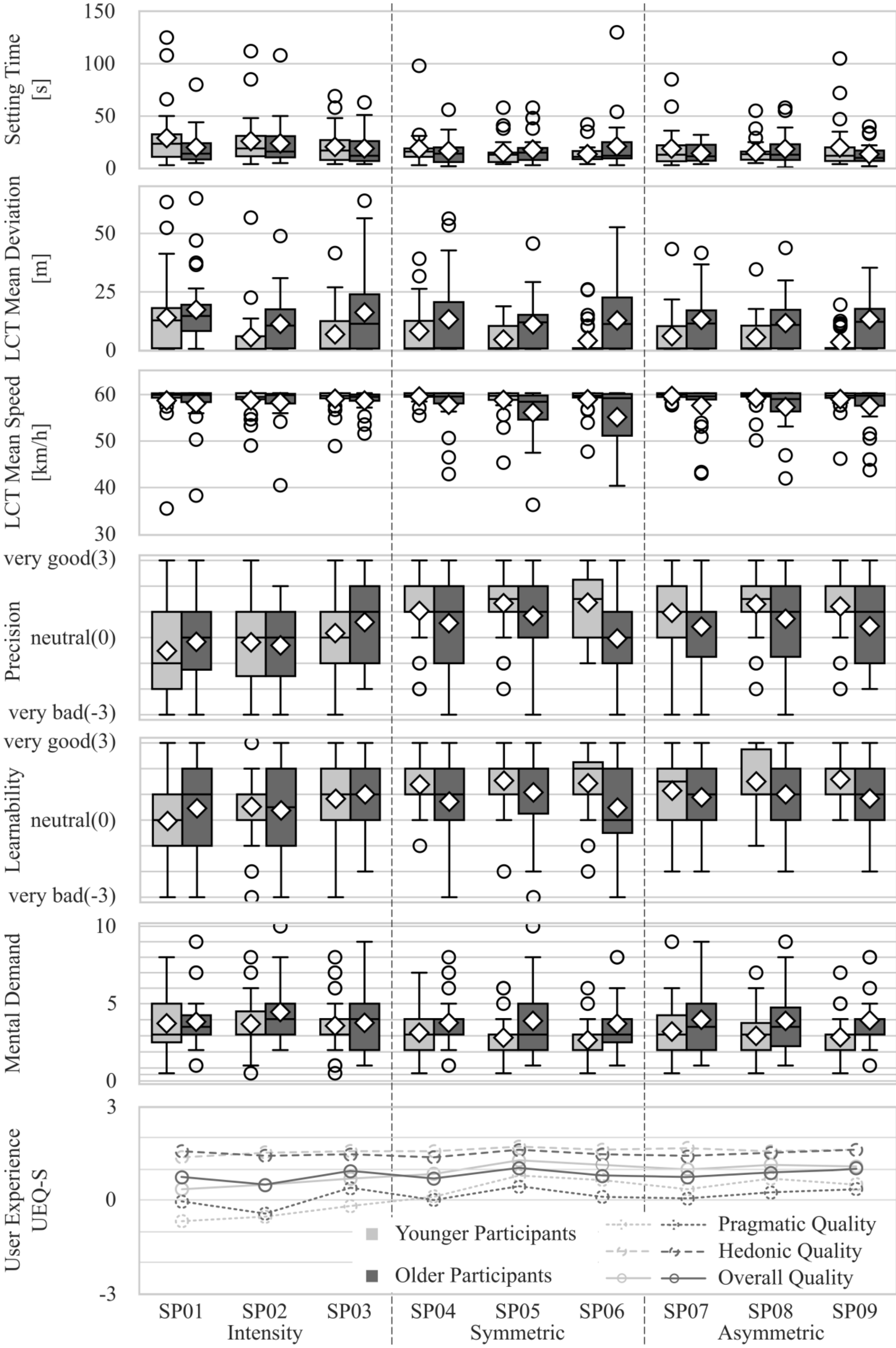

Figure 6 – Results of the study with younger participants in light and older participants in dark colour
Note: The means are marked with a diamond. For the mental demand, 0 equals very low and 10 equals very high.

4. DISCUSSION

Three of the older participants did not feel the mid-air haptics at all. These were written down, and no measurements were recorded for the SP for these participants. These three participants were all male and aged between 69 and 79 years. Even higher non-recognition rates of mid-air haptic feedback also occurred in the last study in the project [22] with roughly 30% of participants not feeling the mid-air haptic feedback. The modulation frequency was changed from the last study to this study, from 50 to 80 Hz, and the feedback type from line on the middle finger to circle on the palm with a diameter of 16 mm. This seemed to have increased the recognition rate based on the assumption that the participants represented the same variety of the population. It remains unclear if the non-recognition rate can be further lowered by an improved mid-air haptic unit or if it is just due to the decreasing tactile sensitivity through changes in the mechanoreceptors of the skin [16–19].

Due to some participants not feeling every SP, the number of participants was not the same for every SP (indicated later by the number (N) in the test statistics). IBM SPSS V 28.0.0.0 was used to investigate the significance of the results (*Tables 2* and *3*). The significance between the age groups for the task fulfilment was investigated with the exact test of Fisher due to low numbers of frequencies (*Table 2*). No significant differences in task fulfilment were found. For the rest of the evaluation parameters, the Mann-Whitney U-test was used to investigate the significance between the age groups. For the setting time, no significant differences between the two age groups were found. For the LCT mean-deviation significant differences were found for SP03 (U = 489.000, r = .300, p = .028, N = 54), SP05 (U = 525.000, r = .296, p = .027, N = 56), SP07 (U = 488.000, r = .292, p = .032, N = 54) and SP08 (U = 543.000, r = .336, p = .012, N = 56) and very significant differences for SP02 (U = 479.000, r = .410, p = .003, N = 51), SP06 (U = 539.000, r = .366, p = .007, N = 55) and highly significant differences for SP09 (U = 587.000, r = .530, p < .001, N = 54). For SP05 (U = 270.500, r = .262, p = .050, N = 56) and SP06 (U = 256.500, r = .276, p = .040, N = 55), significant differences for the LCT mean speed were found between the two age groups.

*Table 2 – The significance between age groups is assessed for task fulfilment with the exact test of Fisher and else with the Mann-Whitney U-test; *p < .05, **p < .01, ***p < .001*

Parameter	SP01	SP02	SP03	SP04	SP05	SP06	SP07	SP08	SP09
Number of participants	N = 51	N = 51	N = 54	N = 54	N = 56	N = 55	N = 54	N = 56	N = 54
Task fulfilment	X^2 = .427 p = .652	X^2 = .057 p = 1.0	X^2 = .037 p = 1.0	X^2 = 2.070 p = .232	X^2 = 1.829 p = .253	X^2 = 1.569 p = .277	X^2 = .237 p = .724	X^2 = 1.723 p = .263	X^2 = 1.043 p = .347
Setting time	U = 279.500 r = .145 p = .299	U = 301.500 r = .060 p = .671	U = 336.00 r = .063 p = .645	U = 326.500 r = .085 p = .532	U = 445.500 r = .122 p = .361	U = 441.000 r = .143 p = .288	U = 334.500 r = .070 p = .609	U = 403.500 r = .030 p = .824	U = 309.500 r = .125 p = .357
LCT Mean dev	U = 394.000 r = .149 p = .287	U = 479.000 r = .410 **p = .003****	U = 489.000 r = .300 **p = .028***	U = 431.000 r = .162 p = .235	U = 525.000 r = .296 **p = .027***	U = 593.000 r = .366 **p = .007****	U = 488.000 r = .292 **p = .032***	U = 543.000 r = .336 **p = .012***	U = 587.000 r = .530 **p < .001*****
LCT Mean speed	U = 315.500 r = .053 p = .707	U = 301.000 r = .061 p = .664	U = 308.500 r = .128 p = .348	U = 301.500 r = .144 p = .289	U = 270.500 r = .262 **p = .050***	U = 256.500 r = .276 **p = .040***	U = 309.000 r = .130 p = .340	U = 286.500 r = .228 p = .088	U = 325.500 r = .087 p = .521
Precision	U = 364.500 r = .108 p = .439	U = 304.000 r = .018 p = .898	U = 412.500 r = .120 p = .379	U = 302.000 r = .146 p = .284	U = 319.000 r = .160 p = .232	U = 204.000 r = .401 **p = .003****	U = 290.500 r = .177 p = .193	U = 326.000 r = .144 p = .281	U = 261.000 r = .246 p = .070
Learnability	U = 395.500 r = .192 p = .171	U = 317.500 r = .018 p = .900	U = 384.00 r = .052 p = .702	U = 275.500 r = .211 p = .120	U = 338.500 r = .120 p = .369	U = 253.500 r = .287 **p = .033***	U = 326.500 r = .091 p = .505	U = 315.000 r = .169 p = .205	U = 240.500 r = .297 **p = .029***
Mental demand	U = 341.000 r = .046 p = .743	U = 404.000 r = .216 p = .124	U = 379.000 r = .040 p = .769	U = 437.500 r = .181 p = .184	U = 488.000 r = .220 p = .099	U = 497.000 r = .277 **p = .040***	U = 436.500 r = .173 p = .203	U = 490.500 r = .225 p = .093	U = 484.000 r = .296 **p = .030***

For the precision rating, very significant differences between the two groups were found for SP06 (U = 204.000, r = .401, p = .003, N = 55). Significant differences between the age groups were found for learnability for SP06 (U = 253.500, r = .287, p = .033, N = 55) and SP09 (U = 240.500, r = .297, p = .029, N = 54). For SP06 (U = 497.000, r = .277, p = .040, N =55) and SP09 (U = 484.000, r = .296, p = .030, N = 54), significant differences for the rating of mental demand were found between the two age groups.

Bravais-Pearson correlation tests were used for all SPs to investigate correlations between PSA and the parameters (*Table 3*). Only for SP06, there was a small negative correlation between PSA and learnability found (r = -.266, p = .049, N = 55). For SP02 (r = -.300, p = .032, N = 51), SP06 (r = -.320, p = .017, N = 55), SP08 (r = -.299, p = .025, N = 56) significant and for SP09 (r = -.382, p = .004, N = 54) very significant negative correlations for PSA and mental demand were found. For SP05 (U = 521.500, r = .295, p = .027, N 56) and SP07 (U = 484.500, r = .292, p = .032, N = 54) significant differences and for SP02 (U = 488.000, r = .449, p = .001, N = 51), SP06 (U = 546.500, r = .401, p = .003, N = 55), SP09 (U = 509.500, r = .353, p = .009, N = 54) and SP03 (U = 520.500, r = .379, p = .005, N = 54) very significant differences and for SP08 (U = 589.500, r = .446, p < .001, N = 56) highly significant differences were also found between the sexes for rating of the mental demand with the Mann-Whitney U-test (last row of *Table 3*). There were small correlations with r = -.299 to r = -.382 found between PSA and mental demand for SP02, SP06, SP08 and SP09. However, on SP02, SP03 and SP05-SP09 also significant differences with r = .292 (SP07) to r = .449 (SP02) for mental demand between sexes were found, which suggests that the subjective rating of mental demand could be influenced more by sex than by the difference in PSA. Another study by Dittmar et al. showed before that women rate mental demand higher than men [36].

Table 3 –The significance of the Bravais-Pearson correlation between parameters and palm surface area

Parameter	SP01	SP02	SP03	SP04	SP05	SP06	SP07	SP08	SP09
Number of participants	51	51	54	54	56	55	54	56	54
Task fulfilment	r = .136 p = .336	r = -.063 p = .663	r = -.190 p = .169	r = -.019 p = .894	r = -.124 p = .364	r = .125 p = .364	r = -.213 p = .121	r = -.121 p = .375	r = .094 p = .498
Setting time	r = -.048 p = .736	r = .015 p = .914	r = .053 p = .703	r = -.054 p = .697	r = .007 p = .957	r = -.019 p = .892	r = .137 p = .323	r = -.084 p = .538	r = -.025 p = .856
LCT Mean dev	r = -.081 p = .568	r = -.022 p = .876	r = -.001 p = .993	r = .012 p = .929	r = -.087 p = .523	r = .032 p = .815	r = -.009 p = .948	r = -.150 p = .270	r = .053 p = .701
LCT Mean speed	r = .044 p = .758	r = -.146 p = .305	r = .125 p = .368	r = -.003 p = .980	r = -.056 p = .680	r = .139 p = .312	r = -.118 p = .396	r = -.044 p = .749	r = -.196 p = .154
Precision	r = -.143 p = .317	r = -.058 p = .690	r = -.058 p = .677	r = -.132 p = .340	r = -.110 p = .421	r = -.124 p = .366	r = -.017 p = .900	r = -.091 p = .504	r = -.084 p = .547
Learnability	r = -.160 p = .263	r = -.136 p = .342	r = -.234 p = .089	r = -.117 p = .398	r = .045 p = .743	r = -.266 **p = .049***	r = -.025 p = .859	r = -.008 p = .955	r = .054 p = .696
Mental demand	r = -.173 p = .224	r = -.300 **p = .032***	r = -.106 p = .446	r = -.155 p = .263	r = -.244 p = .070	r = -.320 **p = .017***	r = -.209 p = .129	r = -.299 **p = .025***	r = -.382 **p = .004****
Mental demand (female – male)	U = 410.500 r = .240 p = .087	U = 488.000 r = .449 **p = .001****	U = 520.500 r = .379 **p = .005****	U = 464.500 r = .253 p = .063	U = 521.500 r = .295 **p = .027***	U = 546.500 r = .401 **p =.003****	U = 484.500 r = .292 **p = .032***	U = 589.500 r = .446 **p < .001*****	U = 509.500 r = .353 **p = .009****

*Note: In the last row, the significant difference between female and male participants assessed with the Mann-Whitney U-test is shown for the parameter mental demand; *p < .05, **p < .01, ***p < .001*

Although SP06 had the highest task fulfilment rate for both groups, with 51.9 % for younger and 33.3 % for older participants, SP05 achieved higher or the same ratings as SP06 for precision and learnability. The highest UEQ-S rating was also given for SP05 for hedonic with 1.75 and pragmatic quality with 0.82 by the younger, and for hedonic with 1.62 and pragmatic quality with 0.47 by the older participants. However, for SP06 also the most significant differences between the two age groups were found for objective (LCT mean deviation and LCT mean speed) and subjective parameters (precision, learnability and mental demand) as shown in *Tables 2* and *3*. SP04 shows the next high task fulfilment rate and lower LCT mean speed differences between the groups with similar learnability, precision and mental demand ratings as SP05 and SP06, as shown in *Figure 6*. As SP04 to SP06 are all characteristic points with symmetric adjacent snap distances, it can be concluded that this implementation was preferred by the younger and older participants. The preference for characteristic points with symmetric adjacent snap distances has also been shown by Schmid et al. [25] for rotary control elements before. In summary, it could be suggested that age has a bigger influence than palm surface area on primary task performance (LCT mean deviation, LCT mean speed) and also secondary task performance (task fulfilment, setting time).

This study is limited in terms of measuring the palm surface area only via software, and high standard errors between the manual and software measured lengths of hands. An additional limitation is that participant sometimes held their hand still above the mid-air haptics device for more than three seconds, and the slider value was therefore saved automatically, although they were not finished with setting the slider yet. A stopwatch to measure the whole setting time and restarting the software based slider value tracking was used to account for that.

5. CONCLUSION

The study showed that age has a greater impact on performance in the primary and secondary tasks than the individual's palm surface area. A symmetric characteristic point with 1.6–2.5 times larger snap distances (SP04-SP06) led to the best results in terms of task fulfilment and subjective ratings such as precision and learnability. When implementing a virtual slider with gesture control and mid-air haptics in a practical application, it is important to use the full available feedback intensity and to implement, i.e. for a middle point of a scale, a symmetric characteristic point. The occurring non-recognition of mid-air haptics by older participants shows that usability testing with older participants is crucial when planning to use mid-air haptic feedback in a practical application.

In the next study of the research project, the findings between the two age groups will be evaluated at a higher driving speed of 130 km/h in a more immersive static driving simulator at the institute. The additional use of eye-tracking in this simulator is hoped to lead to more insights if the mid-air haptic has the off-road glance reduction potential found by Harrington et al. [2].

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