Analysis of Visual Performance during the Use of Mobile Devices While Walking

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Abstract. Mobile computers and smartphones are often used while their users are walking. From an ergonomic viewpoint, this requires a thorough design of the user interface. Although styleguides provide multiple recommendations there is little known about basic human factors' issues. This study provides recommendations for the visual design by analyzing the influence of walking on visual acuity with a mobile computer. N=22 volunteers participated in the experiment comparing visual acuity during standing, slow walking and fast walking. Additional conditions referred to indoor (treadmill) and outdoor (free walking) situations. The results show that walking speed has a highly significant influence on visual acuity. The results are independent of the indoor or outdoor condition. The decrease of visual acuity is similar to a row on a common eye chart. For compensating this decrease, letters and icons on a mobile device should be enlarged by about 20%.

Keywords: Dynamic visual acuity, DVA, smartphone, walking, mobile use, letter size.

1 Introduction

Technological improvements have let to small-sized displays of smartphones with increasing resolution and, thus, an increasing number of pixels per inch. Today's smartphones offer maximum resolutions beyond visual perception. Because of this it is possible to display miniaturized and undersized letters and icons, which cannot be perceived without extra efforts. Furthermore, small and light-weight mobile devices are frequently used concurrently with other activities. Users often text, retrieve information or check e-mails whilst walking. It is obvious that this might be dangerous, especially for pedestrians in situations with a lot of traffic. But it is always frustrating and increases workload if the visualization is hampered by too small letters or icons. Although their size might still be suitable for interaction while the users are sitting or standing, it is too small for a reliable interaction while walking and simultaneously paying attention to the environment.

During recent decades pixel size has minimized for hand-held mobile devices. While a PDA such as the Apple Newton H1000 was built with a display with 79.4 ppi in 1993, the Dell Axim X50v 2004 provided 216 ppi 10 years later. In 2010, an iPhone 4 or an iPod touch (4. Generation) included a display with 326 ppi. Recent

D. Harris (Ed.): EPCE 2014, LNAI 8532, pp. 133–142, 2014.

devices as the HTC One possess up to 468 ppi. This development makes e.g. the display of full-HD Videos possible, but it also comes along with a miniaturization of elements of the user interface. Considering a common distance between user's eye and device, the resolution is sufficient to display letters and icons in a minuscule size beyond normal eyesight. This is important to remember when designing user interfaces for these devices.

Visual acuity is an individual trait which is measured following a standardized procedure. According to ISO 8596 [1], visual acuity is determined using Landolt C optotypes. A "Landolt broken ring" consists of a circular ring with a gap, therefore resembling a "C". The position of the gap is varied resulting in eight different varieties of the optotype. The participant states the location of the gap. In the following the size of the optotype is reduced until errors in the participant's responses exceed a predefined rate of errors. The size of the gap and the distance between the participant and optotype determines the angle taken as the measure for the visual acuity (Minimum Angle of Resolution, MAR). The logarithmized angle (logMAR) defines normal vision at 0.0 logMAR. Steps of 0.1 logMAR are identical to the rows on an eye chart.

This standard is based on static conditions and no individual movement is considered. Nevertheless, reading tasks often involve movement of either the reader or the object. This is usually the case during walking or driving. To consider the resulting effects, visual acuity is sub-divided into static visual acuity (SVA) and dynamic visual acuity (DVA). DVA is defined as the ability to discriminate the details of an object while there is relative movement between participant and the object [2]. DVA can be measured during voluntary ocular tracking of moving objects. Relative movement is induced by moving either the display or the participant's body or head [3, 4]. A test with moving objects is obtained by rotating optotypes of different sizes in the field of view. Rotation velocity is reduced until the participant perceives the optotype correctly. This way a threshold can be determined for each rotation velocity and optotype size, respectively [5]. With a static optotype, the participant rotates the head voluntarily at a specific angular velocity. The stimulus is displayed when the specific velocity is reached. The control of the experimental conditions is difficult for such a setup [6]. In another study the participants were rotated by a mechanism. Compared to the previous setup with a self-paced rotation, the rotated participants achieved less DVA [7]. Nevertheless, there is no standardized procedure to measure and to describe DVA by now.

An angular velocity of less than 2°/sec has no effect on the visual acuity [8]. The DAV decreases with higher angular velocities. The eye's tracking ability is exceeded at a speed of more than 50 °/sec, and discrimination of stimuli is impossible [3]. Further factors affecting DVA are for instance contrast [9] or personal traits like age, gender or experience in certain sports [6].

SVA and DVA correlate, whereas correlation fades with increasing angular velocity [2, 3]. Nevertheless, correlation is low. In order to assess individual performance in certain tasks, both, DVA as well as SVA, should be considered [10].

Measuring DVA includes just a small range of well-controlled motion. Dynamic visual tasks in every-day life hardly take place under such controlled conditions. Especially during walking, speed and direction of most parts of the body change continuously. Although the head is usually stabilized during walking, it although moves at an amplitude of 5-9 cm, a speed of 0,25-0,35 m/s and a rotation of 5° ± 2,5° (Mean ± SD), which results in a maximal angular velocity of 30°/s ± 8°/s [11].

There are few studies about DVA while participants are walking. One of these compares SVA while standing with DVA while running on a treadmill at a speed of 6.4 km/h. Optotypes (numbers) were presented at a distance of 2 m. Results show that SVA is significantly lower than DVA while running [12]. In another study, the distance between user and object was analyzed as an additional factor. The participants performed a test with Landolt-rings displayed at a distance of 4 m and 50 cm respectively. For a distance of 4 m there was no significant difference between SVA and DVA. But for a distance of 50 cm the visual acuity decreased by 2.3 rows according to ISO 8596 [13]. Another study referred to the influence of walking with different speeds on legibility of normal text and pseudo text on a mobile phone. The results show that visual performance decreased with increasing speed (1.5 km/h, 3 km/h and self-paced speed of 3.4 - 4.5 km/h). Error rate increased and reading time decreased [14]. However, letter size was not considered.

In addition, the biomechanics of walking also effect visual acuity [12]. But because of multiple changing translational and angular speed of the hand-arm-shoulder system, the amount of influence on visual acuity is uncertain and varies [11]. Therefore, it is hard to calculate the effect precisely.

The focus of this study is to predict the actual change in visual acuity using a smartphone while walking. This is especially important because of increasing display resolution and undersized letters.

The baseline hypothesis following the rationale is that walking has a negative effect on visual acuity compared to standing. In addition, it is hypothesized that the effect increases with walking speed.

Studies focusing on walking are frequently carried out applying treadmills in laboratory setups. This allows for a strong control of environmental factors (e.g. light, walking speed, distraction) and other variables. Data collection is usually easier because of additional equipment for measuring and data storage. But a comparative study of free walking vs. walking on a treadmill reveals differences for certain joint kinematics and other temporal variables [15, 16]. According to an usability study the added value of conducting the evaluation in field additionally to the treadmill was found to be very little [17]. In a further study, reading comprehension and word search tasks were administered while walking free vs. treadmill, both inside a laboratory. Therefore, light conditions were identical. The authors found no influence of walking condition on performance, but some differences in subjective measures [18].

As a consequence, this study also considers and investigates a potential effect of the treadmill and other laboratory characteristics on visual acuity.

The purpose of this study is to determine and quantify the influence of walking on visual acuity in a laboratory setup on a treadmill and in an outside setup facilitating free walking.

2 Method

2.1 Participants

N=22 (13 male, 9 female) participants volunteered to take part in the experiment. They were aged 31,0 ± 5,4 (Mean ± SD). Their individual static visual acuity was measured using a standard vision screening instrument (Rodenstock R22, examination disc 119) according to ISO 8596 prior to the experiment [1]. All participants had normal or corrected to normal vision (LogMAR $\leq$ 0.0).

2.2 Apparatus

Well-established and standardized tests are available to measure visual acuity [1]. But for a more sophisticated analysis the single value for visual acuity of such standardized tests is insufficient. Instead, the psychometric function is analyzed. This function resembles the cumulative distribution function of a normal distribution. Characteristics are described by PSE (Point of Subjective Equality) and JND (Just Noticeable Difference). At PSE the number of correct stimuli equals the number of incorrect stimuli. JND describes the slope of the function and resembles standard deviation, but refers to 25% and 75 % recognition rate.

An adequate data basis is required to determine an individual psychometric function. It has to provide sufficient data especially in the range close to the PSE. An adaptive double-staircase-procedure was applied to cover this requirement. In this procedure the size of a stimulus depends on the individual performance at the preceding stimulus. If the first stimulus was determined correctly, the size of the following one is reduced. In the other case the size of the following stimulus is enlarged [19].

Furthermore, the procedure of the visual acuity according to ISO 8596 describes a SVA test. But this present study requires a test for DVA. Therefore the standard SVA test was adapted for the dynamic scenario. It is also based on the optotype Landolt-ring. Each stimulus was presented separately and followed by a screen which allowed for the selection of the correct ring (see Fig. 1). Presentation time was 1 sec.

The visual test was presented on an Apple iPod Touch, 4th generation, which provides a so-called "retina" 3.5" multi-touch display with 326 ppi. This equals a pixel-size of 0,078 mm.

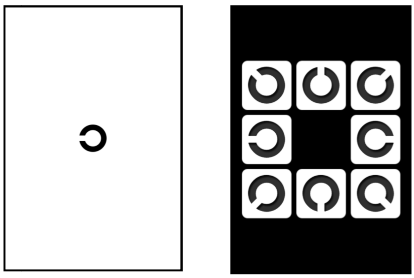

Fig. 1. Stimulus optotype Landolt-ring (left) and selecting interface (right)

The visual acuity refers to an angular value. This requires measuring both: stimulus size and distance between eye and stimulus. Therefore, position of the head and device were logged by an infrared motion tracking system (in the “inside” laboratory condition) and distance was calculated afterwards. For the outdoor condition, measuring system based on a visual marker on the device, a camera, and a subsequent pattern recognition was applied.

The participants kept a minimum distance between eye and smartphone of 45 cm. When the measured distance was below this limit, feedback was provided to the participant in order to correct the distance.

Walking speed is highly adaptable, but there are several attempts to identify “normal” or “preferred” walking speed. The average speed was found to be 4.92 - 5.04 km/h in adults, with an average of 4.62 km/h for females and 5.16 km/h for males [20]. In a meta-analysis regarding 41 studies with 23.111 participants the authors found an average of 4.9 – 5.2 km/h for males and 4.8 - 5 km/h for females. Therefore, we selected “normal” walking speed at 5 km/h and “slow” walking speed at 2.5 km/h.

The experiment was conducted in a laboratory for the condition “inside”. The experimental apparatus included a treadmill, which facilitated walking speeds of 2.5 and 5 km/h (see Fig. 2, on the left). Illumination of experimental area matched ISO 8596 [1].

The condition “outdoor” was carried out in a straight, shady, quiet, tarred road in the vicinity of the institute (see Fig. 2, on the right). Weather conditions such as rain or bright sunshine were excluded. The participants practiced to keep the walking speed of constantly 2.5 and 5 km/h and achieved a precision of ± 0.2 km/h.

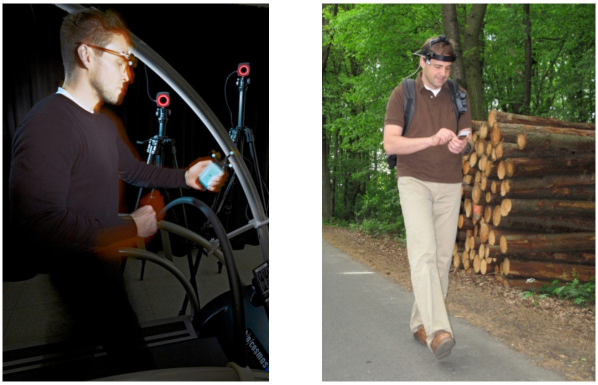

Fig. 2. Participant performing the experiment during the indoor/laboratory (left) and outdoor condition (right)

2.3 Design and Procedure

A 3 x 2 design with repeated measures on both factors was used for the study.

The first factor “walking” was varied in three levels: “standing” (0 km/h), “slow” walking (2.5 km/h) and “normal” walking (5 km/h). To exclude any sequence effects, order of conditions was permuted. Participants were assigned randomly to a permutation.

The second factor “environment” consisted of the conditions “indoor” and “outdoor”. Because of weather, the condition “outdoor” was carried out two months later than “indoor”.

Each experimental session started with a standard SVA test and a short introduction to the mobile DVA test. Subsequently, the participants were equipped with the distance measuring equipment. The following task consisted of fulfilling three double-staircase procedures (240 – 300 stimuli) per condition.

The psychometric function was determined for each participant in each condition. The characteristic parameters of the psychometric function, point of subjective equality (PSE) and just noticeable difference (JND), were calculated. They were considered as dependent variable in the following statistical analysis.

2.4 Statistical Analysis

The statistical distribution of all data sets was tested by a Kolomogorov-Smirnov test for normal distribution. All data showed normality. The three-level factor “walking” was tested by a Mauchly-test and no violations of sphericity occurred. Consequently, a 2x3 MANOVA with repeated measures on both factors was carried out. In case of significant differences, a pairwise comparison (Bonferroni corrections) followed for the three-level factor “walking”. A significance level of 5% was used for the statistical analyses.

3 Results

The results of the statistical analysis show an influence of walking on visual acuity.

For PSE the smallest logMAR was found “standing”/“outdoor”, while the highest was “fast”/“indoor”. The values for both conditions are summarized in Table 1.

Table 1. Mean and standard deviation of PSE in logMAR

	indoor			**Outdoor**		
	standing	slow	normal	standing	slow	Normal
mean	-.2184	-.1466	-.1228	-.2287	-.1397	-.1402
SD	.08657	.08920	.11048	.08230	.07316	.07591

The repeated measures MANOVA revealed a highly significant influence of “walking” ($F_{(2.42)}$=37.12, p<0.01, η^2=0.639). “Environment” ($F_{(1.21)}$=0.341, p=0.566, η^2=0.016) as well as the interaction ($F_{(2.42)}$=0.655, p=0.525) had no effect on PSE.

A multiple comparison (Bonferroni correction) showed significant differences for the levels “standing” and “slow” (p<0.01) and “standing” and “fast” (p<0.01) but not for “slow” and “fast”. The significant difference was 0.08 logMAR (“standing”/“slow”) and 0.092 (“standing”/“fast”) which almost equals a row on an eye chart. An illustration of the results is given in Fig. 3.

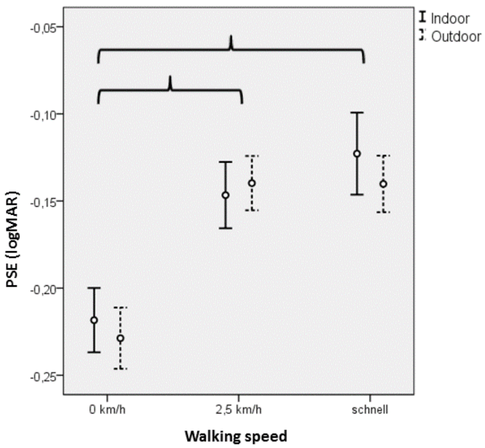

Fig. 3. Means and SD for PSE, parentheses indicate significant differences

The results for the measure of dispersion JND varied from 0.740 to 0.976, whereas the highest results occurred at “fast”/“outdoor”. Means and SDs for all conditions are given in Table 2.

Table 2. Mean and standard deviation of JND in logMAR

	indoor			**outdoor**		
	standing	slow	normal	standing	slow	normal
mean	.0754	.0740	.0818	.0787	.0849	.0976
SD	.03357	.03120	.02689	.03601	.03746	.03443

The following repeated measures MANOVA showed a significant influence of the factor “walking” ($F_{(2.42)}$=3.837 p=0.029, η^2=0.155), but no influence for “environment” ($F_{(1.21)}$ =0.341, p=0.566, η^2=0.016) and no interaction respectively ($F_{(2.42)}$=0.535, p=0.589).

Bonferroni-corrected multiple comparison revealed a significant difference for “standing”/”fast” (p=0.034) as well as “slow”/”fast” (p=0.035). The differences amounted to 0.013 („standing“/“fast“) and 0.010 („slow“/“fast“), respectively. Fig. 4 illustrates the statistical values.

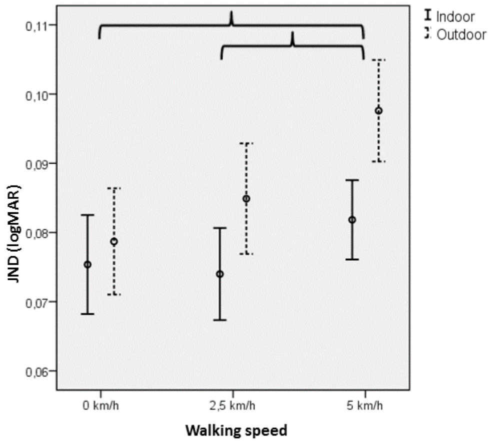

Fig. 4. Means and SD for JND, parentheses indicate significant differences

4 Discussion

This study proofs an influence of walking on dynamic visual acuity. Visual acuity is highest while users are standing and DVA is reduced while they are walking. This matches with the results of Hillmann und Bloomberg [12] and Peters und Bloomberg [13], respectively. In contrast to the results of Peters und Bloomberg who found a reduction of 2.3 rows of an eye chart, we found a reduction of one row only. This difference could be caused by the fact that Peters und Bloomberg used a stationary chart for their experiment, while participants held the smartphone in their hands in this study. Therefore, the participants were able to compensate head movements using their hand-arm-shoulder-system.

Another result is that only walking has an effect on visual acuity as opposed to standing. Walking speed does not affect PSE and, thus, DVA. The effect occurs even at low speeds. One conclusion is that speed reduction does not help to improve visual acuity. But there are other ways to compensate the loss in visual acuity. This is by either shortening the distance between eye and device or by adapting the size of letters and icons. It can be achieved by enlarging letters or icons by about one row of an eye chart, which equals to 20%.

JND was susceptible to walking speed. The slope of the psychometric function flattens in fast walking compared to slow walking. Faster walking also triggers incorrect detections of PSE-exceeding optotypes. This may result in an increasing number of errors. This effect can be reduced by adapting the walking speed and slow walking.

The environmental situation showed no effect on visual acuity. This corresponds to the findings of studies concerning performance measures [17, 18]. Other studies showed an influence of treadmill walking on physiological measures [15, 16]. However, this influence does not extend to visual acuity. It is concluded that our laboratory setting matches well with outside conditions and results are transferable. Nevertheless, in our outdoor setting environmental factors including light were limited to a comparatively small range. Moreover, the outdoor setup was characterized by few or no additional distracting stimuli (i.e. pedestrians, cars, or other obstacles).

The results show that walking has a considerable influence on visual acuity for mobile devices. The change in visual acuity results into a reduction of one level on a typical test chart for visual acuity. The slope of psychometric function also flattens for faster walking. This also indicates a less stable performance in visual acuity and results into more errors. Consequently, the display of information has to be adapted or at least adaptable to the different use cases of the mobile device. The sizes of icons and letters should be increased by about 20% to compensate the loss in visual acuity caused by walking. This becomes more relevant if mobile devices are used in traffic situations with a lot of distracting environmental stimuli.

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