# Evaluation of Precision, Accuracy and Threshold for the Design of Vibrotactile Feedback in Eye Tracking Applications

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## Abstract

A novelty solution for controls of assistive technology represent the usage of eye tracking devices such as for smart wheelchairs and robotic arms [10, 4]. In this context usage supporting methods like artificial feedback are not well explored. Vibrotactile feedback has shown to be helpful to decrease the cognitive load on the visual and auditive channels and can provide a perception of touch [17]. People with severe limitations of motor functions could benefit from eye tracking controls supported with vibrotactile feedback. In this study fundamental results will be presented in the design of an appropriate vibrotactile feedback system for eye tracking applications. We will show that a perceivable vibrotactile stimulus has no significant effect on the accuracy and precision of a head worn eye tracking device. It is anticipated that the results of this paper will lead to new insights in the design of vibrotactile feedback for eye tracking applications and eye tracking controls.

## 1 Introduction

Artificial vibrotactile feedback is nowadays a commonly applied method for smart devices, to inform the user about events such as receiving text messages [3]. Studies in the field of vibrotactile feedback associated with myoelectric prostheses [1, 11] and stroke rehabilitation [6, 15] indicate benefits in reducing cognitive load in learning tasks and the ability to maintain a sense of touch. Most of current literature focuses on stimulating the hand or arm. Applications for stimulus locations such as the head and chest can function as guidance by vibrotactile vests or belts [2, 12]. In military operations the cognitive workload of the auditive and visual channel was reduced by using such vests as navigation aid [13].

Injuries of the upper spine can lead to quadriplegia. The patients can be assisted by autonomous guided wheelchairs [10] and robotic arms moved by visual cues as shown by various authors [4, 18, 9, 5]. Transferring the findings of vibrotactile feedback in assistive technology controls can lead to the above mentioned advantages. Due to a possible lack of tactile sensation in the upper body and extremities of the users, the head is an appropriate possibility to apply vibrotactile feedback in order to research learning behaviors and support the collaboration between the assistive system and human. As stated by Choi and Kuchenbecker vibrotactile feedback has to follow certain design rules. Among others, the stimulus has to be perceivable, the strength has to be adjusted and unintentional perceptual effects must be excluded [3]. Suggestions for feedback designs in the area of the head and temple are scarce. Myles and Kalb are stating, a wrong designed vibrotactile feedback can lead to nausea, headaches, dizziness, disorientation and aversion to the systems [13]. The information gap on the design of vibrotactile feedback leads to different outcomes of user experience and motor learning tasks [16].

Vibrotactile feedback applied to eye tracking glasses is mostly unexplored. Few researchers evaluated the usage and effects of vibrotactile feedback in this context. Outcomes show that haptic feedback is increasing the completion time of gaze gestures depending on the duration of the stimulus [7]. Further, the design of multimodal feedback for eye tracking glasses was evaluated in different studies. The results show that placement is crucial for well-matched feedback [2, 13, 14]. As stated an optimized feedback stimulus has to be perceivable and distinguishable [3]. Few studies exist on sensation threshold measurements in the region of the head and temple. Myles and Kalb stating perceivable thresholds around 2 µm. Outcomes showed that low frequencies are better perceivable than high frequencies and were evaluated at 32 Hz, 54 Hz and 63 Hz [13]. Stuart et al. stated thresholds depending on age between 28 µm and 107 µm [17]. Empirical data of the comfort of vibration feedback in the area of the temple is not stated.

Eye tracking devices are sensible against movement, changing light sources, and other parameter changes such as calibration and fit to the head [19, 20]. It is pending, if vibration is a leading cause in a loss of accuracy and precision. A main reason for the lack of information is that most eye tracking applications are focusing on user experience and environmental evaluation. Tobii Technologies and Thibeault et al. are giving methods to evaluate these conditions to compare different eye tracking setups, which will be applied in this study [19, 20].

Regarding this information the focus in this publication is bilateral. In the first study, vibrotactile threshold

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measurements at the temples are performed. The outcomes are used to determine an appropriate vibrotactile feedback regarding amplitude and frequency for the second study. The data from a head worn eye tracking device will be evaluated on precision and accuracy. Possible differences generated by the vibrotactile stimulus attached to the glasses will be evaluated by comparing measurements with and without feedback. A first estimation on the sensation of the feedback, stated by the participants will be presented.

# 2 Methods

In the first study, a threshold measurement was performed in the temporal region. In the second study the eye tracking glasses with a vibrotactile stimulus, realized by a vibration coin motor, were evaluated on precision and accuracy.

Ten adults (6 males and 4 females) with a mean age of 34 (SD 10) ranging from 24 to 55 years, agreed to participate in both studies. None of the participants stated medical conditions with the eye muscles or tactile perception. No medical conditions such as headaches, nausea or dizziness were stated by the participant in the duration of the study. The study was reviewed and approved by the ethic commission of the University of Siegen. All participants read, agreed and signed the informed consent forms before conducting the studies.

## 2.1 Vibration perception threshold of the temporal region

A piezo element (PK2FVP2, ThorLabs) was used as stimulus. The characterization of the amplitude in µm over AC-voltage is shown in **figure 1** for both tested frequencies. 54 Hz resembles the frequency explored by Myles and Kalb, which provides insights in the comparability of the results and the apparatus with the literature [13]. 140 Hz resembles the frequency created by the vibration coin motor used in the second study. Due to the limitations of the setup the usable range for the threshold measurement lies between 2.48 µm and 5.27 µm. Even though the curve is non-linear the threshold measurements were not interrupted when participants stated higher or lower thresholds than the usable range.

A customized 3D-printed casing was built to contain the piezo element. The casing was fixed on the head with a scotch tape. The pressure of the piezo towards the head was adjusted so that the piezo element and skin were in contact. To measure the threshold the transformed Up/Down Method introduced by Wetherill and Levitt with 3up/1down was conducted [8]. The piezo element was placed perpendicular to the skin. The participants were told to state if the stimulus was perceivable with yes or no answers. The amplitude was adjusted by setting the voltage in 0.1 V steps corresponding to a difference in amplitude of 60 nm for the linear range. 50 measurements

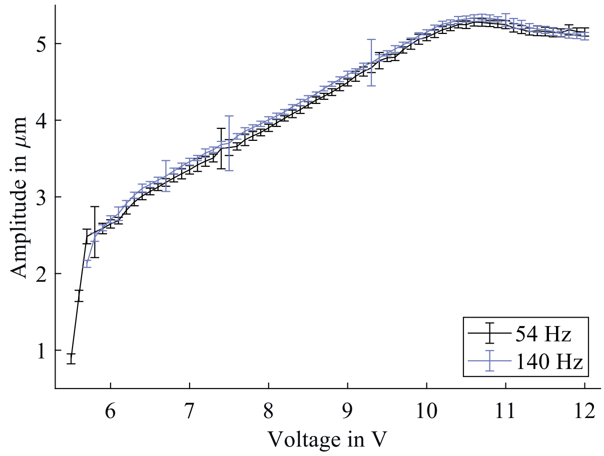


**Figure 1** Characterization of amplitude over voltage for the piezo element used as vibration stimulus in study one.

were taken for each participant and frequency. The pulses of the stimulus lasted at most 1 second. The study was paused after every 10 measurements for a short interval to avoid adaptation.

The threshold was estimated as 79.37% of all answers stated with a perceivable vibration in the temporal region [8]. To evaluate the results the psychometric function was fitted to the data by using a generalized linear regression model with MATLAB as presented by Wichmann and Hill [22]. The standard deviation is used to evaluate the results regarding the reliability of the participants statements.

## 2.2 Measurement of accuracy and precision in an eye tracking task with vibrotactile stimulation

The apparatus consisted of the eye tracking glasses and a 3D-printed casing for the vibration coin motor (PMD, 310-122). The illuminance was set to 480 lx. The board shown in **figure 2** was placed centrally in front of the participant's eye level. It contained 14 visual markers referred to as points. The spacial distribution was adopted as stated by Thibeault et al. [19]. Differing to Thibeault the distance to the visual stimuli was set to 1 m, since shorter distances resulted in unpleasant head positions or inability to see all points in the scene camera clip. To keep the same distance in every measurement a chin rest was utilized in the study. The points were arranged in circles with angles of 7, 15 and 19 to the center point. Each point had a diameter of 2 cm. The inner circle of the reference point had a diameter of 2 cm and the outer circle 3 cm.

The vibrotactile stimulus was set to a frequency of 140 Hz. The amplitude was measured as 75 µm characterized with a laser vibrometer (OptoMET Dual Sense I). At these settings the vibration was audible. Since learning behaviors weren't focused in this study, no further steps were taken to prevent a perception of the auditive feedback. All participant stated, that the vibration was perceivable in the temporal region.

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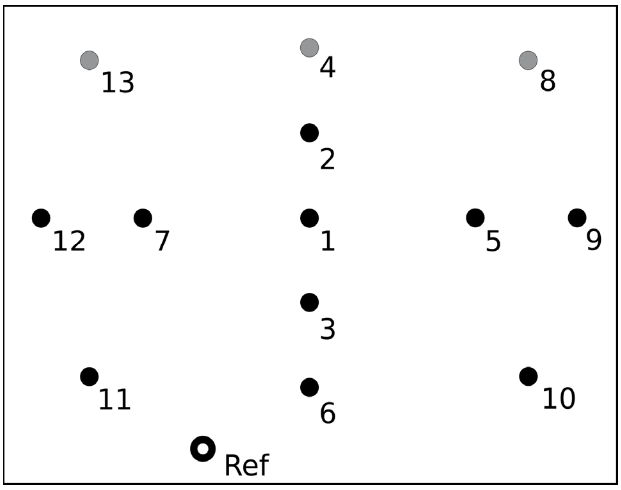


**Figure 2** Visual stimuli for the second study. The participants were told to focus on the given points. The black circle represents the reference guidance for synchronization. The gray points represent excluded points from the evaluation as discussed in the results.

A chin rest and chair were adjusted to the height of the participants to position the middle point at eye level. If necessary, the glasses were adjusted with different nose pads and calibrated as stated in the manual [21]. The head position was adjusted so that all points were detected by the scene camera of the glasses and fixated by the users without discomfort in positioning and eye movement. Eight measurements were conducted, alternating between deactivated (Condition A) and activated (Condition B) vibrational stimulus, to reduce the impact of habituation effects and human errors. Each point was focused for three seconds. After each measurement a short survey was conducted regarding the sensation of the glasses and the casing, the sensation of the auditive and vibrotactile feedback. First the participants had to indicate the sensation on a scale from one (very pleasant) to five (very unpleasant). If the sensation was stated by a level greater three, further questions to the occurrence of this decision were asked.

The data analysis was conducted with MATLAB. The raw data was exported with Tobii Pro Lab. Following the median were formed of each point and each participant. The precision was calculated as stated in Thibeault as RMS of the standard deviation in x and y direction [19]. Accuracy was determined by a sliding window method to calculate the smallest distance between all evaluated points for each measurement. The distance was given by vectors between the optimal position of the point found by the sliding window and the measured point. The median and median absolute deviation for each measurement and participant was calculated and evaluated. Both precision and accuracy were transformed from pixel in mm for a better comparison of the results. These results were evaluated on significant differences between the conditions by using a one-way within-subjects ANOVA. Due to non-significant results, further evaluations of variance were not conducted. Thibeault's results stated worse outcomes in the periphery of the glasses for precision and accuracy. This hypothesis was tested by grouping point 1, 2, 3, 5 and 7 and point 6, 9, 10, 11 and 12 in two groups building the median.

# 3 Results

## 3.1 Study One - Vibration perception threshold of the temple

The threshold measurement was conducted with all participants. In five cases, the threshold wasn't determined, due to the limits of the system. The maximum threshold of the setup was not sufficient to be perceived by the participants. Observations showed that some of the excluded participants could sense the stimulus at different locations of the head such as the forehead or cheekbones. The participants who perceived the vibration with its amplitude of a maximum of 10.7 µm were in average 29 years old. Participants who couldn't perceive the stimulus were in average 43 years old.

The measured thresholds can be seen in **table 1**. The measurements for participant 7 (P7) with a frequency of 54 Hz were conducted, but in the evaluation process excluded, since the stated answers weren't consistent. The threshold for Participant 10 with 140 Hz exceeded the limitations of the setup, as seen in the excluded measurements. The standard errors calculated as standard deviations showing rather high deviations in contrast to the amplitude. This can be attributed to the rather small step size.

| | P5 | P6 | P7 | P8 | P10 |
|---|---|---|---|---|---|
| Age | 30 | 25 | 28 | 27 | 35 |
| T1 | 2.40 | 4.16 | 4.23 | 3.87 | - |
| SD1 | 0.13 | 0.39 | 0.15 | 0.23 | - |
| T2 | 0.74 | 3.88 | - | 3.56 | 5.27 |
| SD2 | 0.18 | 0.19 | - | 0.28 | 0.21 |

**Table 1** Results of the threshold measurement. T1 represents the results for the threshold measurement with a frequency of 140 Hz. T2 was measured with a frequency of 54 Hz. All threshold values are given in µm. SD1 and SD2 shows the standard deviation corresponding to each frequency.

## 3.2 Study Two - Measurement of accuracy and precision

For each participant and point, the median was formed from a data set of 150 samples and transformed into the order shown in figure 2. The gray points (4, 8, and 13) were excluded from the following analysis because not enough data was recorded for more than half of the measurements. Depending on the head position the points exceeded the scene camera clip. The data of participant 2 was excluded, due to systematical errors.

The data was evaluated both for each measurement and each point for each participant on its precision and

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accuracy as seen in **figure 3**. Even though the precision varied for each participant (ANOVA: F = 4.541, p = 0.0001) no significant differences between measurements with and without stimulus can be found. The precision for each point varied between 3.34 mm and 31.96 mm. In figure 3 the median values for all points in each measurement and each participant are shown. In measurements with an even number the stimulus was activated. Same stimulus-criterion apply to the accuracy measurements. No significant differences were found (ANOVA: f = 0.929, p = 0.4916). In between points significant differences were found. The accuracy ranged 20.29 mm to 29.17 cm. Tendencies to higher accuracy between measurement 1, 2, 3 and 4 can be found. No significant differences between condition A and condition B could be found (F = 1.118, p = 0.3652). Further investigations in the accuracy between points on different radii were taken in focus. It shows that the error in accuracy is lower on the inner points than on the outer points for 8 out of 9 participants. The data of the integrated gyroscope was evaluated to determine changes in head positions leading to changes in gaze point differences. The mean changes in all participants were -1.26 deg/sec (SD 5.06 deg/sec), resulting in differences of approximately 2 cm/sec.

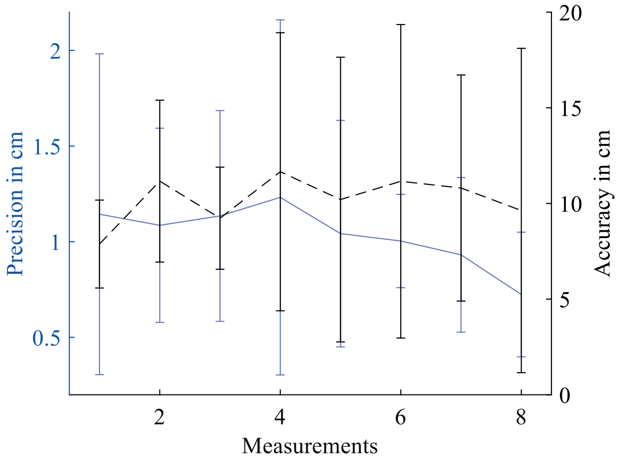


**Figure 3** Shown are the means for precision and accuracy over the conducted measurements. Tendencies to higher accuracy in cases with activated stimulus exists. Yet no significant differences between conditions was found, shown by the standard derivation.

As stated above, the participants were asked to evaluate the experience of the glasses and casing, the vibration and the auditive cue resulting from the vibrating motor. The eye tracking device was rated as pleasant in all measurements (mean 2.07, SD 0.53). The vibrotactile feedback was rated as neutral to unpleasant with a mean of 3.34 (SD 0.94). Auditive feedback was rated with 2.96 (SD 1.07). The participants tended to stay at the same statement and adjust it with a maximum of one point in between all measurements. The participants evaluated the vibrotactile feedback as too strong and the vibration is noticeable over the whole glasses. Main reasons for an unpleasant auditive feedback experience were the volume and pitch of the motor.

# 4 Discussion

First the outcomes of study one and study two will be discussed separately. Overarching conclusions will be presented between both studies and outlooks to the design of vibrotactile feedback in eye tracking applications, threshold measurement setups and findings for eye tracking controls.

The results of the threshold measurements can be compared to the outcomes of Myles and Kalb for the temporal region [13]. Myles and Kalb stated thresholds around 2 µm. Since thresholds vary regarding to the age, type of stimulation as well as skin and medical conditions, the study setup and design is shown to be applicable for further measurements. Furthermore, Myles and Kalb are stating that higher frequencies than 160 Hz are not recommended for tactile feedback with head application, since auditive feedback creates irritation in usage. These results can be supported with the evaluated data. Table 1 shows for all participants higher thresholds for the frequency of 140 Hz. In study two the assessment of the auditive feedback supports this statement. As Stuart et al., stated age is a reason the threshold tend to rise [17]. Regarding the group exceeding the possible amplitude levels these findings can be agreed. An average an age difference of 14 years lies between both groups.

Regarding the setup and procedure, the step size of the threshold measurement should be increased. In figure 1 the standard deviation has approximately the same size as the step size. It is anticipated that a larger step size leads to more accurate outcomes of the thresholds, due to less variation of the answers. This will lead to a reduced standard error and more reliable data. The vibration was audible as soon as the piezo was activated. Since the volume of the noise varied slightly with the change of the amplitude in the non-linear regions an overlap of the effects cannot be excluded. A reduction of the noise was not possible due to the bone conduction of the sound waves. The measurable range of amplitude should be increased to receive thresholds of all participants.

In the second study the precision and accuracy were not significantly affected by the vibration, even though the videos showed blurry recordings when the vibration motor was active. The errors of the precision and the diameter of the points are correlating. It has to be mentioned that points were excluded. The precision for these points couldn't be evaluated. The points were positioned at the border to the visual field of the scenic camera. The pupil wasn't well detected in this area, which lead to the loss of data in the 3 second fixation of the points. No filters are applied to the raw data. Indications for the low error could be the number of samples used for the calculations.

Accuracy errors found in this study rise up to a maximum of 29 cm. The outer points are showing greater variances than points in the center of the visual field. This was also shown by Thibeault [19]. This error can occur by

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different correlations. The distance to the board may vary slightly with each measurement, since the participants were allowed to move the head between the measurements. As mentioned before the errors of the periphery points were included in the evaluation of the accuracy. Scaling weights can be used to reduce the accuracy error. This was not integrated in the evaluation process, since differences between both conditions were of interest. Unintended head movements occurred in the measurement as shown by the evaluation of the gyroscope data. Since it is assumed that calibration errors repeat for all measured points a resulting error can be excluded by using the sliding window method. Nevertheless, this error has to be regarded in other studies. The found accuracy errors for a distance of 1 m are tolerable for studies of user experience. To control a wheelchair or robotic arm, such accuracy errors can lead to errors and inaccurate positioning. Among others, gaze gestures or longer dwell times are used to reduce the error occurring by fixating an object with the eyes. If the accuracy error has to be minimized it is suggested to apply an independent calibration.

Eye tracking based controls can be used with this setup if the object is centered in the field of view to minimize errors in precision and accuracy. Regarding people with reduced motor control, methods such as gaze gestures should be considered. Vibrotactile Feedback with a frequency of 140 Hz and an amplitude of 75 µm should not cause extensive errors with the glasses. Regarding the assessments of the participants the strength of the vibrotactile feedback should be reduced. Amplitudes with a height of 30 µm to 50 µm should be chosen. Considering the results from both studies and the literature these amplitudes should be perceivable for most users and should not result in aversion. The optimal vibrotactile feedback setup should be inaudible. The frequencies should be lowered to reduce the sound of the vibration motor. Literature shows, that the frequency has to be adapted to the application. Concluding the vibration transmission over the glasses can lead to aversion of the setup. Different locations for the stimulus are suggested to minimize the shaking of the glasses, such as behind the ear.

# 5 Conclusion

The use of vibrotactile feedback were evaluated for eye tracking glasses. Threshold measurements and empirical surveys in study two indicated feasible intervals for amplitudes of vibrotactile feedback at the temple. Differences on the precision and accuracy of measurements with and without applied vibrotactile feedback showed no effects. The applied vibration was characterized as an amplitude of 75 µm and a frequency of 140 Hz. Therefore, it is concluded, that vibrotactile feedback can be used with the glasses. The control of smart wheelchairs and robotic arms for handicapped people should be supported by additional calibrations to reduce errors in accuracy.

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# 7 Literatur

[1] Antfolk, C.; D'Alonzo, M.; Rosén, B.; Lundborg, G.; Sebelius, F.; Cipriani, C.: Sensory feedback in upper limb prosthetics in Expert review of medical devices, 2013, 10, 1, p. 45–54

[2] Borg, E.; Rönnberg, J.; Neovius, L.: Vibratory-coded directional analysis: Evaluation of a three-microphone/four-vibrator DSP system. In Journal of Rehabilitation Research and Development, 2001, 38, 2, p. 257–263

[3] Choi, S.; Kuchenbecker, K.J.: Vibrotactile Display: Perception, Technology, and Applications. In Proc. IEEE, 2013, 101, 9, p. 2093–2104

[4] Cio, Y.L.; Raison, M.; Leblond Menard, C.; Achiche, S.: Proof of Concept of an Assistive Robotic Arm Control Using Artificial Stereovision and Eye-Tracking in IEEE Engineering in Medicine and Biology Society, 2019, 27, 12, p. 2344–2352

[5] Dragomir, A.; Pana, C.F.; Cojocaru, D.; Manga, L.F.: Human-Machine Interface for Controlling a Light Robotic Arm by Persons with Special Needs in Healthcare, 10, 1, 2021, p. 1–6

[6] Enders, L.R.; Hur, P.; Johnson, M.J.; Seo, N.: Remote vibrotactile noise improves light touch sensation in stroke survivors fingertips via stochastic resonance in J Neuroeng Rehabil., 2013, 10, 105

[7] Kangas, J.; Rantala, J.; Akkil, D.; Isokoski, P.; Majaranta, P.; Raisamo, R.: Vibrotactile stimulation of the head enables faster gaze gestures in International Journal of Human-Computer Studies, 2017, 98, pp. 62–71

[8] Kingdom, Frederick A. A.; Prins, Nicolaas: Psychophysics. A practical introduction. 1. ed., 2010, Amsterdam: Elsevier.

[9] Krishna Sharma, V.; Saluja, K.; Mollyn, V.; Biswas, P.: Eye Gaze Controlled Robotic Arm for Persons with Severe Speech and Motor Impairment in In ACM Symposium on Eye Tracking Research and Applications (ETRA '20 Full Papers). Association for Computing Machinery, New York, NY, USA, 2020, Article 12, 1–9

[10] Leaman, J.; La H.M.: A Comprehensive Review of Smart Wheelchairs: Past, Present and Future, 2017, available online at http://arxiv.org/pdf/1704.04697v2

[11] Moore, C.H.; Corbin, S.F.; Mayr, R.; Shockley, K.;

Silva, P.L.; Lorenz, T.: Grasping Embodiment: Haptic Feedback for Artificial Limbs. In Frontiers in neurorobotics, 2021, 15

[12] Myles, K.; Binseel, M.S.: The Tactile Modality: A review of tactile Sensitivity and human tactile Interface. Fort Belvoir, VA., 2007

[13] Myles, K.; Kalb, J.T.: Guidelines for Head Tactile Communication. Fort Belvoir, VA, 2010

[14] Rantala, J.; Kangas, J.; Akkil, D.; Isokoski, P.; Raisamo, R.: Glasses with haptic feedback of gaze gestures in CHI EA 2014: One of a ChiNd - Extended Abstracts, 32nd Annual ACM Conference on Human Factors in Computing Systems, 2014, p. 1597-1602

[15] Seim, C.E.; Wolf, S.L.; Starner, T.E.: Wearable vibrotactile stimulation for upper extremity rehabilitation in chronic stroke: clinical feasibility trial using the VTS Glove, NeuroEngineering Rehabil, 2021, 18, 14

[16] Sigrist, R.; Rauter, G.; Riener, R.; Wolf, P.: Augmented visual, auditory, haptic, and multimodal feedback in motor learning: a review in Psychonomic bulletin and review, 2013, 20, 1, p. 21–53

[17] Stuart, M.; Turman, A.B.; Shaw, J.; Walsh, N.; Nguyen, V.: Effects of aging on vibration detection thresholds at various body regions in BMC Geriatrics, 2003, 3, 1

[18] Sunny, Md S. H.; Zarif, Md I. I.; Rulik, I.; Sanjuan, J.; Rahman, M.H.; Ahamed, S.I.: Eye-Gaze Control of a Wheelchair Mounted 6DOF Assistive Robot for Activities of Daily Living, 2021, available at Research Square [https://doi.org/10.21203/rs.3.rs-829261/v1]

[19] Thibeault, M.; Jesteen, M.; Beitman, A.: Improved Accuracy Test Method for Mobile Eye Tracking in Usability Scenarios. In Proceedings of the Human Factor and Ergonomics Society Annual Meeting 2019, 63, p. 2226-2230.

[20] Tobii Technology: Accuracy and precision test method for remote eye trackers. Retreived from $https://stemedhub.org/resources/3311/download/Tobii\_Test\_Specifications\_Accuracy\_and\_PrecisionTestMethod\_version\_2\_1\_1.pdf$, 2011

[21] Tobii AB: Tobii Pro Glasses 2 User's Manual, Version 1.1.3. Retreived from https://www.tobiipro.com/siteassets/tobii-pro/user-manuals/tobii-pro-glasses-2-user-manual.pdf, 11/2020

[22] Wichmann, F. A.; Hill, N. J.: The psychometric function: I. Fitting, sampling, and goodness of fit in Perception and psychophysics 2001, 63, 8, p. 1293–1313.