Haptic perception in people with deafblindness

Does haptic perception in people with deafblindness differ from people with normal vision and hearing?

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Abstract

This paper investigates the question whether people with deafblindness have a better haptic perception than people with normal vision and hearing. The motivation for this work is that previous research has indicated that it is typical to compensate for the loss of one sense by developing a superior other sense, but has not investigated whether this also counts for deafblindness. Hereby, it is interesting to focus on haptic perception because haptics are often used in communication for people with deafblindness. To solve this knowledge gap, we tested the performance of seven people with acquired deafblindness and their seven age- and gender-matched controls in an experiment. Haptics was tested using three standardized tests to capture the performance on haptic perception: the two-point discrimination task for spatial tactile acuity, the Von Frey filaments for tactile sensitivity and just noticeable difference weights for haptic force feedback. Results showed that people with deafblindness were better than their matched controls in spatial tactile acuity and tactile sensitivity, but surprisingly not in haptic force feedback. This can implicate that people with deafblindness have lower thresholds for passive touch than people with normal vision and hearing, but in active touch there does not seem to be a difference. Measured body location (arm, hand or finger) appears to influence the result. More research needs to be done to elaborate this result, taking differences in people with deafblindness into concern.

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1. Introduction

Different studies prove that it is natural to compensate for the loss of one sense by developing a superior other sense (Lewald, 2013; Rettenbach, Diller & Sireteanu, 1999, Ptito et al., 2012). This compensation is also visible in brain activity. The occipital lobe, the part of the brain responsible for vision (Sadato et al. 1996), can be reorganized, as well as the auditory cortex, the part of the brain responsible for auditory information (Bola et al., 2016). A recent study even used a whole-brain approach and found specific increases in connectivity in areas involved with motor processing in blind people (Bauer et al., 2017). These results support the 'cross-modal processing' capabilities of the brain, like when the occipital cortex in blind individuals processes sensory information from other senses (Siuda-Krzywicka et al., 2016). A considerable amount of sensory research has been done on participants with sensory deprivation, like blind or deaf people, while little research has been done on people with dual sensory impairment: people with deafblindness (Dammeyer, 2014; Moller, 2003).

Deafblindness is a combined hearing and vision disorder which can be caused by various reasons (Moller, 2003). People with deafblindness are not always completely blind and deaf. Instead, various gradations occur. A precise definition lacks, but in the current study criteria of deafblindness from Damen and Worm (2013) are used. People with deafblindness have a visual acuity of less than 0.3 and/or a visual field of less than 30° (compared to a visual acuity of 1 and a visual field of 90° temporally to central fixation, 60° inferiorly and 50° superiorly and nasally in average healthy adults (Spector, 1990)). Additionally, they have a hearing loss of 26 dB or more in the better ear (compared to a hearing range in healthy adults being 0 dB to 120 dB (Wold, Blum, Keislar, & Weaton, 1996)). Also, it should be considered that deafblindness should be seen as an individual disability, not just a synthesis of not being able to see and hear. Having to deal with being deaf as well as being blind adds more limitations to one's daily life, and this makes the impact much larger (Damen & Worm, 2013).

Three types of deafblindness are distinguished: congenital deafblindness occurs from birth or before the development of language (Dammeyer, 2014), acquired deafblindness starts after the development of language but before the age of 55 (Moller, 2003), and elderly deafblindness occurs from the age of 55 (Vaal et al., 2007; Rönnberg & Borg, 2001). Due to our aging population, the number of people in this last group is growing rapidly. Estimated is that in the UK approximately 356.000 people had impairments in both hearing and vision in 2010 and in 2030 that number will be 569.000. (Robertson & Emerson, 2010). This growing prevalence makes it necessary to invest more in research for people with deafblindness since they experience more difficulties in day to day life. Those difficulties can be overcome by innovations that arise out of knowledge through research.

One of the daily issues that people who experience deafblindness run into is limitations in their communication with the world around them. Lack of communication is a problem since people with deafblindness are prone to facing isolation (McLetchie & MacFarland, 1995), and in preventing this problem, communication is critical. Communication goes mostly through their haptic sense since they cannot use the senses which are primarily used for communication (i.e., visual and auditory). The use of the haptic sense is visible in the ways of communication that are used by individuals with deafblindness, like Braille, tactile fingerspelling, and using the fingers to feel vibrations on the talkers' throat when he speaks: the Tadoma language (Aitken, Buultjens, Clark, Eyre, & Pease, 2000). In effect, this limits the ability to communicate with people who do not understand these haptic languages, which is the vast majority of the world.

Bartiméus, an institute that provides care, education, and training for partially sighted or blind people (www.bartimeus.nl), aspires to design a new communication device for people with deafblindness based on haptics. The current research will help them with some of the specifics in designing this device. To gain more information on how new ways of communication can be developed, it is important to understand whether and how the haptic perception of people with deafblindness might differ from people without deafblindness.

The current study, therefore, aims to answer the following question: Does haptic perception of people with deafblindness differ from the haptic perception of people without deafblindness? This study will be a pilot, to inquire whether it is feasible to involve more participants and elaborate a bigger research in the haptic perception of people with deafblindness. There have been studies on tactile perception and tactile memory in individuals with deafblindness, but only using case studies, participants with congenital deafblindness, or specific components of tactile functioning that were not generalizable (Arnold & Heiron, 2002; Janssen, Nota, Eling, & Ruijssenaars, 2007).

Haptic perception has many facets that can be measured using standardized tests. Together with Bartiméus, we will use three tests to map out what aspects of haptic perception differ in people who have deafblindness. The following theoretical section will introduce these three tests and associated theory: *spatial tactile acuity, tactile sensitivity,* and *haptic force feedback.* These three aspects were chosen as they represent the two senses contribute to haptics: the tactile sense and kinesthetic sense (Kammermeier, Kron, Hoogen, & Schmidt, 2004). The tactile sense works by different types of receptors in the skin (Ferrington, Nail, & Rowe, 1977), and the kinesthetic sense is the perception of body movement and forces (McCloskey, 1978). The tactile sense (passive touch – being touched) will be tested by spatial tactile acuity and tactile sensitivity, haptic force feedback will test the kinesthetic sense (active touch - touching).

Spatial tactile acuity

Spatial tactile acuity, a way to determine how innervated a part of the body is (Brown, Koerber, & Millecchia, 2004), characterizes the tactile sense. It has been found that people who use braille as a form of communication have superior spatial tactile acuity test scores compared to people who do not use braille

(Noh et al. 2015). Moreover, blind subjects typically outperform sighted counterparts in other spatial tactile acuity tests (Norman & Bartholomew, 2011).

One of the tests that is often used in determining spatial tactile acuity is the two-point discrimination task (TPD). TPD measures the capability to distinguish two stimuli presented at the same time with equal pressure to the participant's skin. The task is to tell whether either one or two points are pressing the skin (Alsaeed, Alhomid, Zakaria &, Alwhaibi, 2014). The TPD test has been used for over 100 years in a lot of different studies since Weber introduced it in 1835 (McLeod, in Cope & Antony, 1992). One of the most important conclusions until now is that generally, the smallest distance between the two points of the whole skin on the body is noticeable on the fingertips (Proctor & Van Zandt, 2008), which means they are the most sensitive for spatial tactile acuity.

Given this previous work, the current study will test different parts of the body on spatial tactile acuity using the TPD task. Expected is that people with deafblindness have a smaller TPD distance than people without deafblindness, and are therefore better at spatial tactile acuity, especially on the fingertips.

Tactile sensitivity

Tactile sensitivity, the threshold of which a stimulus is felt on the skin, is another inquiry of the tactile sense. Research shows that individuals who use Braille have a lower threshold of tactile stimuli compared to those who do not use Braille (Noh et al., 2015). Normally, younger subjects have a lower threshold than older subjects. However, the average blind subject has the tactile threshold of an average sighted subject of the same gender, but 23 years younger (Goldreich & Kanics, 2003). These studies suggest that individuals who are blind or use braille can perform tasks of tactile sensitivity better than people who are sighted or do not use Braille. Also, it is shown that congenitally deaf people show enhanced tactile sensitivity (Levänen & Hamdorf, 2001). These enhancements present that people with sensory impairments can have a lower tactile sensitivity threshold, and raise the question whether individuals with dual sensory impairments experience the same effects.

Tactile sensitivity will be tested with Von Frey filaments (VFf). The VFf are a threshold test that use different diameter steel threads to determine at what thickness of the thread the participant can feel the stimulus (Johansson, Vallbo, & Westling, 1980). In the current study it is expected that, given the previous research, participants with deafblindness have a lower tactile sensitivity threshold than people without deafblindness.

Haptic force feedback

The kinesthetic sense will be tested by haptic force feedback, a tactile sensation felt when touching a surface (Banter, 2010). It has been proven that people with hearing disabilities can learn kinesthetically

(Bauman & Murray, 2009). The kinesthetic way of learning is also underlined with the use of tactile sign language by people with deaf(blind)ness.

The kinesthetic sense will be tested with just noticeable difference (JND) weights. It has been demonstrated that blind people tend to be better at discriminating different weights (Grouios, Alevriadou, & Kouidou, 2001). This suggests that blindness can cause compensatory adaptations in the kinesthetic sense.

In the current study, JND weights will be used to test haptic force feedback. Two different weights will be compared successively, to determine the JND. Given the previous studies, the expectation is that people with deafblindness will have a smaller JND than people without deafblindness.

Summary of literature and implications for experiment

It is important that people with deafblindness are provided with suitable ways of communication since regular communication using hearing and vision is not possible for them. Unfortunately, research on deafblindness is limited (Dammeyer, 2014; Moller, 2003), though both practical experience and research suggest that certain haptic functions can be used for communication when the use of hearing and vision declines (Lathinen, 2008 in Van Dijk, 2012). Awareness and insight could help reduce problems that are associated with living with deafblindness. This knowledge gap pleads for more research to help people with deafblindness live a life as normal as possible.

Taken together, the literature review shows that people who have limited sensory ability in one sense (i.e., either vision or hearing loss) tend to perform better on three haptic tests that examine passive and active touch. However, it is not clear whether this is also the case for individuals who have lost sensory capability in two senses, such as in people with deafblindness. Up until now it is not yet known whether the haptic ability of people with deafblindness differs from the haptic ability of people without deafblindness. This is important to study because if this is the case, this can make room for controlled interventions and new techniques.

An experiment consisting of different tests will be conducted on two groups: people with deafblindness, the experimental group, and people without deafblindness, the control group. This study is seen as a proposal for research involving bigger groups when more time can be included. To achieve a fair comparison between groups, the individuals will be matched based on age and gender. Previous work has shown that haptic perception is influenced by age and gender. As people get older, their haptic perception declines in quality (Thornbury & Mistrella, 1981; Norman, Norman, Swindle, Jennings, & Bartholomew, 2009). Also, on average, women outperform men on haptic perception tasks (Boles & Givens, 2011; Goldreich & Kanics, 2003; Kappers, 2003; Woodward, 1992). From the cited literature, it can be hypothesized that participants with deafblindness will score better than the participants in the control group.

2. Methods

2.1. Participants

A total of 14 participants took part in this study, 7 with deafblindness and 7 controls with no visual or auditory impairments. The average age of the participants with deafblindness was $M = 45.14$ with $SD = 12.31$. The average age of the participants in the control group was $M = 45$ with $SD = 12.64$. Specifications and matches that were made can be found in Table 1. Hearing specifications are presented in either decibels (dB) or percentage. Unfortunately, this is not translatable to each other. For a long time, different approaches to estimating hearingloss have been used (Carter, 1943), and since dB and percentages are not comparable, these are hard to translate (Laird, Taylor, & Wille, 1932). Assumed can be that all participants had a minimum hearing loss of 26 dB in the better ear.

Participants with deafblindness were gathered using both personal contacts and contacts of Bartiméus, an institute that helps people with visual impairments. A scientific advisory committee at Bartiméus reviewed relevance and risks for participants, and the research proposal was approved.

Due to the problems in communication with people with congenital deafblindness, in the current research only people with acquired deafblindness participated. They were contacted via e-mail or personally and asked to join the experiment. After collecting the participants with deafblindness, participants for the control group were searched and matched to the participants with deafblindness.

Table 1
Participants with deafblindness are matched on age and gender to people without deafblindness. For specifications of deafblindness characteristics, see Introduction section.

	Participants with deafblindness				Control match	
Match	Age	Gender	Vision	Hearing	Age	Gender
1	63	Male	Blind from 6 years of age	60 dB loss from 53 years of age	60	Male
2	57	Male	Blind from 7 years of age	L: 35% loss, R: 40% loss from work	57	Male
3	53	Male	2-4° from 20 years of age	65% loss from birth	53	Male
4	40	Female	5-10° diagnosed from 23 years of age	75-80 dB loss diagnosed since 23 of age	40	Female
5	43	Female	25° + cataract/macular edema from 30 years of age	80 dB loss on both ears from birth	45	Female
6	35	Male	<10° from 6 years of age	Deaf from birth	35	Male
7	25	Male	10-15°/90% vision since birth	Deaf from 11 years, now CI	25	Male

2.2. *Materials & Stimuli*

2.2.1. *Spatial tactile acuity.*

The aim of spatial tactile acuity is to measure tactile effects. To do this, we used a two-point discriminator (TPD) (see Figure 2A). The TPD measures the smallest separation at which two points applied simultaneously to the skin can be distinguished from one (Gellis & Pool, 1977). This tool had four characteristics, namely distances between two dots of 5 mm, 4 mm, and 3 mm. Also, there was one catch trial with one dot.

The TPD was measured at various locations on the body (see Figure 3). These locations involved 3 places on the lower arm, because most of the tactile communication devices that are already used are placed around the lower arm (for example: Huisman, Frederiks, Van Dijk, & Heylen, 2012; Huisman & Frederiks, 2013). Also, the palm surface and dorsal surface of the hand were tested because this area is used a lot in communication via hand gestures, like tactile fingerspelling. Moreover, the fingertip of the index finger was tested since this is one of the most sensitive areas for humans, due to a large number of tactile afferents in the skin (Johansson & Flanagan, 2009). The fingertips are also used by people with deafblindness in the Tadoma language (Aitken, Buultjens, Clark, Eyre, & Pease, 2000).

Per location, the discriminator was placed on the skin ten times: 5 times two points with a 5 mm difference, 5 times one point in a randomized order. The random order was generated by using the =RAND() function in Excel. The matched control participants received the same random order as the deafblind counterpart. If the participant rated the amount of two dots and one dot correct for 7 times or more in the first round of 5 mm difference, the discriminator was placed on the skin another ten times, now with a distance of 4 mm. In random order 5 times two points with a 4 mm difference, 5 times one point. If the participant had 7 or more correct answers again, the last round was done with 5 times two points with 3 mm difference and 5 times one point. If the participant got 7 or more correct, 3 mm was the final score for this test.

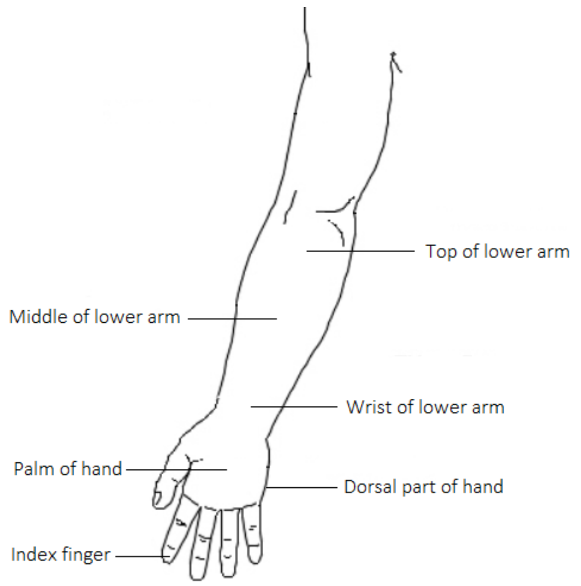

Figure 1. Body locations of testing with spatial tactile acuity and tactile sensitivity.

2.2.2. *Tactile sensitivity.*

In this experiment, Von Frey filaments (VFf) were used. The participants' task was to tell whether a filament was pressing on the skin or not. VFf can be used to assess tactile sensitivity. The test uses steel threads of different thicknesses to determine at what thickness the participants can feel the stimulus. A set of 20 VFf was used, eight of which were employed in this experiment (see Figure 2B and C for two examples). The used filaments are summarized in Table 2. The up-down method, described by Chaplan, Bach, Pogrel, Chung, and Yaksh (1994), was used to examine the effects. The VFf was tested on the same body locations as the TPD test. Filaments were flexed immediately before use, to administer consistent stimulus intensity. The filaments were administered smoothly perpendicularly onto the participant's skin, until the stimulus bended, for two seconds per filament. The experiment started with filament 1 (see Table 2) and went to a thicker filament if the participant did not notice the stimulus. The experiment ended when the participant noted four times that he felt the current stimulus on the correct location. Between the different filaments, there was a 5-second break. Participants could scratch their arm in between filaments since the test could be ticklish.

Table 2

Theoretical values of target force of a standard VFf set used in experiment tactile sensitivity (Bradman, Ferrini, Salio & Merighi, 2015).

Filament	Evaluator Size (mm)	Target force (g)
1	1.65	.01
2	2.36	.02
3	2.44	.04
4	2.83	.07
5	3.22	.16
6	3.61	.40
7	3.84	.60
8	4.08	1.0

2.2.3. Haptic force feedback.

Just noticeable difference (JND) weights were used to test haptic force feedback (see Figure 2D). In this experiment, the participant had to distinguish two different weights, and assess which one was heavier. All the different weights had a similar look, using black granite in a glass bottle and small lead weights to make them heavier when necessary. See Table 3 for an overview of the different weights that were used. Two weights at a time were placed in front of the participants, and they were asked which one was heavier than the other. The whole experiment was carried out in a staircase matter. If the participant gave the correct answer, the difference in the next round would be decreased (and therefore harder to discriminate). If the answer was incorrect, the difference between the two weights would be increased in the next round. If that difference was already tested correctly, the answer would be that specific difference. This is specified in Table 3.

Table 3

Haptic Force Feedback weights and the weights of their comparisons in gram. For example: weight 30.0 was given together with 30.5. If the participant was correct, weight 30.0 was given together with 30.3. If the participant was incorrect, weight 30.0 was given together with 30.7. If one mistake was made, the last comparison before the mistake counted as true.

Weight	Comparison 1	Comparison 2	Comparison 3	Comparison 4
30.0	30.5	30.3|30.7	30.1/30.4|/30.6/30.8	30.1|30.9
45.0	45.5	45.3|45.7	45.1/45.4|/45.6/45.8	45.1|45.9
65.0	65.5	65.3|65.7	65.1/65.4|/65.6/65.8	65.1|65.9
95.0	95.5	95.3|95.7	95.1/95.4|/95.6/95.8	95.1|95.9
140.0	140.5	140.3|140.7	140.1/140.4|/140.6/140.8	140.1|140.9

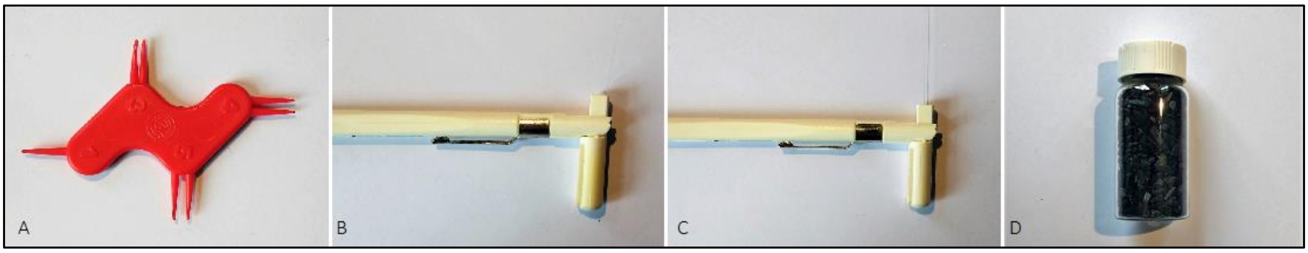

Figure 2. Equipment used in the three experiments: A.) Two-point discriminator, B.) Von Frey filament 1, C.) Von Frey filament 8, D.) Just Noticeable Difference weight.

2.3. Design

The design of this experiment inhered of a matched pairs design, with the experimental group being participants with deafblindness and the matched control group being participants with normal vision and hearing. The groups were classified using the independent variable: whether or not participants were deafblind. The matched pairs design was chosen to produce similar groups as the sample size was small, and random assignment would most likely not produce equivalency of groups that is achieved with a repeated measures design (Cozby, 2009).

The dependent variable consisted of performance on haptic tests and consisted of three parts: spatial tactile acuity, tactile sensitivity, and haptic force feedback.

2.4. Procedure

Beforehand, all participants with and without deafblindness were asked to fill out a questionnaire about their age, gender, and specifications of deafblindness. All participants with deafblindness were tested in their homes, sometimes with a translator present. The participants in the control group were tested at home or at Utrecht University. If no translator was needed, participants were tested unaccompanied.

Before the experiment started, all participants were asked to read or listen to the informed consent and, if they agreed, sign it. The informed consent and information letter were also sent earlier so that they could read this beforehand (see Appendix A). After they gave their signature, the test section of the procedure followed.

The experiment consisted out of three different tests: spatial tactile acuity tested with TPD, tactile sensitivity tested with VFf, and haptic force feedback tested with JND. This task order was consistent for all participants, to keep differences as small as possible. Each task was preceded by an instruction of how the task worked. The arm was placed on a table, so it could not easily move or shift during the experiment. People without deafblindness and people that had some vision left were given a blindfold, so they could not be affected by their sight during the experiments, and performed the test under the same conditions as deafblind people. The experiment was done in a silent environment, in order to avoid side effects from sound.

The first test involved calculating the spatial tactile acuity of the skin. TPD was tested on the six body locations earlier described. The two-point discriminator was placed on the skin of the participant by the researcher. Participants were asked 10 times per body location if they felt 1 or 2 dots touching their skin. If they had enough correct answers, the test was repeated with a smaller difference between the two dots. The TPD task took about 10 minutes per participant.

The second test engaged tactile sensitivity. Tactile sensitivity was determined by calculating a threshold using the VFf. The VFf was placed on the skin of the participant by the researcher until the participant noted a certain VFf 4 times in a row, for all different body locations earlier described. The VFf task took about 10 minutes per participant.

The last test involved haptic force feedback and was tested using JND weights. The participant was asked to, one by one, lift two JND weights that the researcher had placed in front of him, using only their dominant hand. The experiment was done when the participant had reached a clear threshold in all 5 categories. The JND task took about 10 minutes per participant.

The whole examination took about 45 minutes per participant. Participants did not receive an incentive to join the experiments. After the three tests, the nature and purpose of the experiment were fully explained.

2.5. Data analysis

Since the group of participants was small in this research, we represent the data patterns visually and describe the data to reveal patterns. Specifically, the participants with deafblindness and the control group will be compared using boxplots (Tukey style) (Krzywinski & Altman, 2014) and scatterplots. In the scatter plots the data will be jittered in case they have the same value, by adding random values to the categories on the x-axis using (difference score+(RAND()-0.5)/5), so they can still be discriminated in the plot. The scatterplots will contain difference scores, where the scores of the participants with deafblindness will be subtracted from the score of the control group.

For differences between groups and body locations, a Mann-Whiney U test was performed. This test was chosen as an alternative to an unpaired t-test because, although the participants are matched, the two groups are still considered as two independent groups. A standard unpaired t-test was not possible because the assumptions of parametric tests were not tenable.

3. Results

The results are discussed per test. Results of every test contain one table and one jittered scatterplot. Tactile sensitivity and haptic force feedback also contain one boxplot. This was not possible for spatial tactile acuity because the variation in answers was not significant enough to illustrate an understandable boxplot. Next to the visual reproduction, Mann-Whitney U tests are executed.

An overview of the results is given in this segment, a more detailed view of the results can be found in the corresponding Appendix. In figures and tables, participants with deafblindness are noted as DB, participants in the control group as C.

3.1. Spatial tactile acuity

Table 4 shows measures of central tendency, minimum-, and maximum scores. In all different matches, the mean, quartiles, and minimum score could indicate that the participants with deafblindness (*M* = 4.48, *SD* = .73) have the lower thresholds for spatial tactile acuity than the control group (*M* = 4.86, *SD* = .41). This was tested with a Mann-Whitney U test: the average threshold of the deafblind participants (*Mdn* = 4.50) was significantly lower than the average threshold of the control group (*Mdn* = 5) ($U = 644$, $Z = -2.81$ $p < 0.05$ one-tailed). Deafblind, as a group, outperformed non-deafblind. These results are consistent with our hypotheses that deafblind outperform non-deafblind participants on spatial tactile acuity.

Table 4
Mean and standard deviation of individual scores on TPD. Highlighted numbers indicate the lowest threshold of that specific match.

	M		*Mdn*		*Q1*		*Q3*		*Min*		*Max*	
Match	**DB**	**C**	**DB**	**C**	**DB**	**C**	**DB**	**C**	**DB**	**C**	**DB**	**C**
1	4.33	4.83	4.50	5	3.75	4.75	5	5	3	4	5	5
2	4.67	4.83	5	5	4.50	4.75	5	5	3	4	5	5
3	4.67	5	5	5	4.50	5	5	5	3	5	5	5
4	4.67	4.83	5	5	4.50	4.75	5	5	3	4	5	5
5	4.17	4.67	4	5	3.75	4.5	5	5	3	3	5	5
6	4.50	4.83	4.50	5	4	4.75	5	5	4	4	5	5
7	4.33	5	4.50	5	3.75	5	5	5	3	5	5	5

Looking at the individual level, Figure 8 until Figure 14 in Appendix B expose that in all individual pairs, the spatial tactile acuity threshold was lower in the participant with deafblindness compared to their control. Additionally, Figure 3 shows that the average difference scores are above zero when sorted on tested body location. Error bars are calculated using the standard deviation and along with maximum and minimum values (see Table 4) show that there is some variability in the dataset. A big difference in two-point discrimination score is observed at location 5, the Index Finger. This can indicate that the Index Finger is more sensitive to TPD than the rest of the tested locations for people with deafblindness. This was tested using a Mann-Whitney U test. In Table 5 it becomes clear that only on the location Index Finger, the difference was significant.

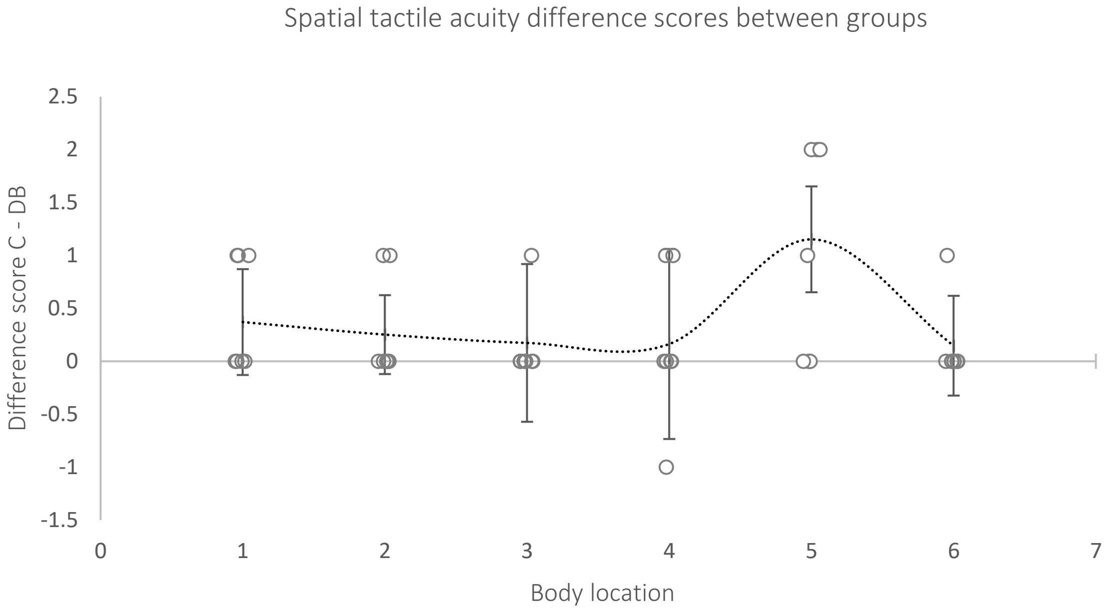

Figure 3. Difference scores of performance on TPD using (scores of controls – scores of deafblind) and jittering overlapping data points using (difference score+(RAND()-0.5)/5) to visualize all the data points. The dotted line corresponds to the average trend. Body location 1-6 represent Arm1, Arm2, Arm3, Palm, Index Finger and Hand dorsal, respectively.

Table 5
Statistics of spatial tactile acuity on testing location. Highlighted locations are significantly different between participants with deafblindness and controls.

Location	*U*	*Z*	*p (1-tailed)*
Arm1	14.0	-1.88	.10
Arm2	17.5	-1.47	.19
Arm3	21.0	-1.00	.36
Palm	21.0	-.63	.36
Index Finger	5.50	-2.64	.06
Hand dorsal	21.0	-1.00	.36

3.2. Tactile sensitivity

Table 6 shows measures of central tendency, minimum-, and maximum scores. Based on the means, participants with deafblindness (*M* = 4.26, *SD* = 1.72) seem to have lower thresholds for tactile sensitivity than the control group (*M* = 6.12, *SD* = 1.23). This is specified in Table 6, which shows that in all matches, the participant with deafblindness showed a lower average threshold on the VFf. This was tested with a Mann-Whitney U test: The average threshold of the deafblind participants (*Mdn* = 4.50) was significantly lower than the average threshold of the control group (*Mdn* = 6) ($U = 312$, $Z = -5.21$, $p < 0.05$ one-tailed). Deafblind, as a group, outperformed non-deafblind. These results are consistent with our hypotheses that deafblind outperform non-deafblind participants on tactile sensitivity.

Table 6

Mean and standard deviation of individual scores on VFf task. Highlighted numbers indicate the lowest threshold of that specific match.

	M		*Mdn*		*Q1*		*Q3*		*Min*		*Max*	
Match	**DB**	**C**	**DB**	**C**	**DB**	**C**	**DB**	**C**	**DB**	**C**	**DB**	**C**
1	4.50	5.83	4.50	6	3.75	5	5.25	6.25	3	5	6	7
2	3.50	7	3.50	7	1.75	6	5.25	8	1	6	6	8
3	4.83	6.67	5	6.50	4	6	5.25	7.25	4	6	6	8
4	5	5.33	5.50	5.50	4.25	4.50	6	6.25	2	3	6	7
5	4	5.17	4	5.50	2.50	3.50	6	7	1	2	6	7
6	4.50	6.17	5	6	3.75	5.75	5	6.50	3	5	5	8
7	3.50	6.67	2	7	1	6	7.25	7	1	6	8	7

Figure 4 suggests that there indeed is a significant difference because the upper quartile of participants with deafblindness is has a lower threshold than the bottom quartile in the control group. The visual representation of the data given in Table 6 gives the impression that participants with deafblindness are better at recognizing the Von Frey filaments as a stimulus compared to participants in the control group.

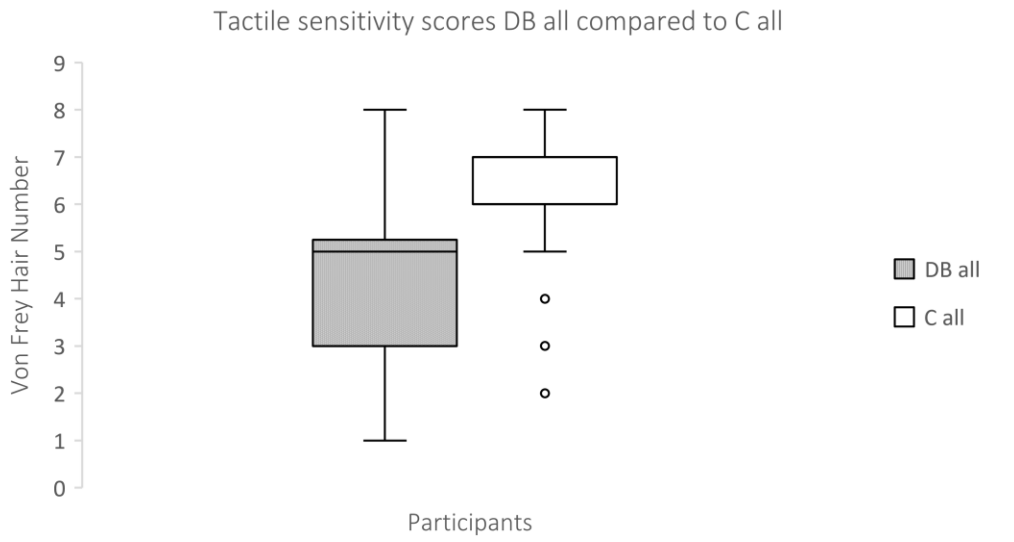

Figure 4. Tactile sensitivity of people with deafblindness (DB all) compared to people without deafblindness, the control group (C all). Median C all = 6, Median DB all = 5.

Looking at the individual level, Figure 15 until Figure 21 in Appendix C expose that in all individual pairs, the tactile sensitivity threshold was lower in the participant with deafblindness compared to their control. Additionally, Figure 5 shows that the average difference scores are above zero when sorted on tested body location. Error bars are calculated using the standard deviation and along with maximum and minimum values show that there is some variability. Testing body location 3 and 6 (Arm 3 and Hand dorsal), seem to elicit the biggest difference scores. Testing body location 5 (Index Finger), shows an opposite effect. This can indicate that the Index Finger is less sensitive to TPD than the rest of the tested locations for people with deafblindness. This was tested using a Mann-Whitney U test (see Table 7). The results show that for all locations, except the Index Finger, the difference between the deafblind and control group is significant.

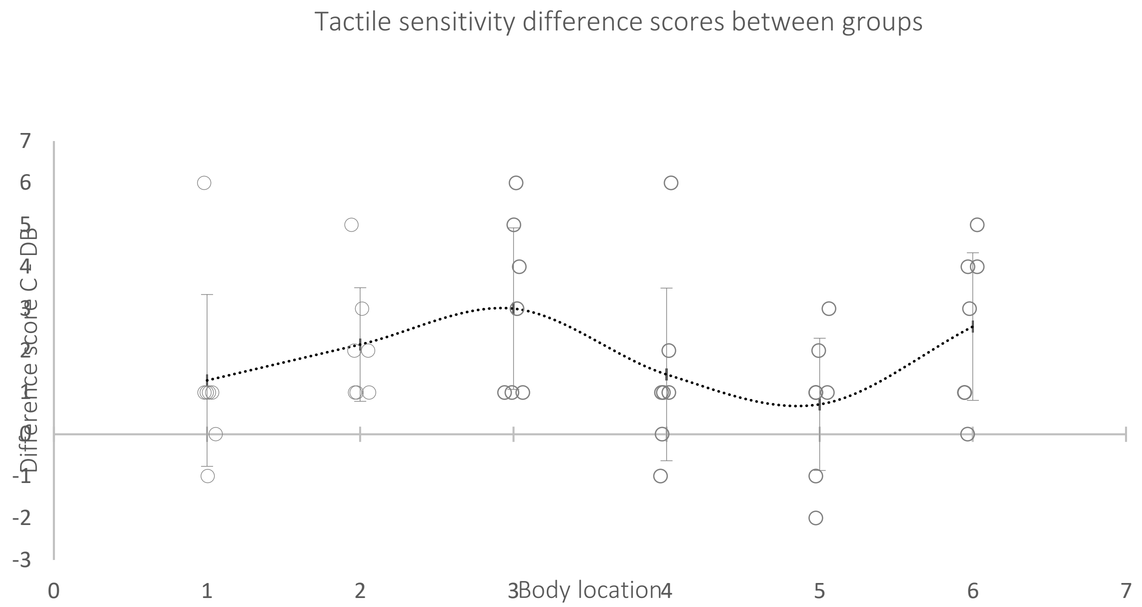

Figure 5. Difference scores of performance on VFf using (scores of controls – scores of deafblind) and jittering overlapping data points using (difference score+(RAND()-0.5)/5) to visualize all the data points. The dotted line corresponds to the average trend. Body location 1-6 represent Arm1, Arm2, Arm3, Palm, Index Finger and Hand dorsal, respectively.

Table *7*

Statistics of tactile sensitivity on testing location. Highlighted locations are significantly different between participants with deafblindness and controls.

Location	*U*	*Z*	*p (1-tailed)*
Arm1	11.0	-1.86	.05
Arm2	3.50	-2.74	.00
Arm3	1.00	-3.06	.00
Palm	11.0	-1.78	.05
Index Finger	15.0	-1.25	.13
Hand dorsal	7.50	-2.21	.03

3.3. Haptic force feedback

Table 8 shows measures of central tendency, minimum-, and maximum scores for the JND test. There does not seem to be a clear difference in scores between the participants with deafblindness (*M* = .30, *SD* = .14) and the control group (*M = .37*, *SD* = .16). This was tested with a Mann-Whitney U test: The average threshold of the deafblind participants (*Mdn* = .30) did not differ significantly from the average threshold of the control group (*Mdn* = .40) (*U* = 16, *Z* = -1.69 *p* > 0.05 one-tailed). These results are not consistent with our hypotheses that deafblind outperform non-deafblind participants on haptic force feedback.

Table 8

Mean and standard deviation of individual scores on JND. Highlighted numbers indicate the lowest threshold of that specific match.

	M		*Mdn*		*Q1*		*Q3*		*Min*		*Max*	
Match	DB	C	DB	C	DB	C	DB	C	DB	C	DB	C
1	.32	.50	.40	.50	.10	.35	.50	.65	.10	.30	.50	.80
2	.24	.26	.20	.30	.15	.20	.35	.30	.10	.20	.40	.30
3	.34	.32	.40	.30	.20	.15	.45	.50	.20	.10	.50	.60
4	.28	.32	.20	.30	.15	.20	.45	.45	.10	.10	.60	.50
5	.26	.32	.30	.40	.10	.15	.40	.45	.10	.10	.40	.50
6	.34	.38	.40	.50	.20	.20	.45	.50	.20	.20	.50	.50
7	.34	.48	.30	.50	.25	.40	.45	.55	.40	.40	.50	.60

Figure 6 shows that the boxplots show considerable overlap. This visual representation of the data given in Table 6 gives the impression that participants with deafblindness are not better at distinguishing just noticeable difference weights compared to participants in the control group. There does not seem to be a difference between participants with deafblindness and the control group on haptic force feedback.

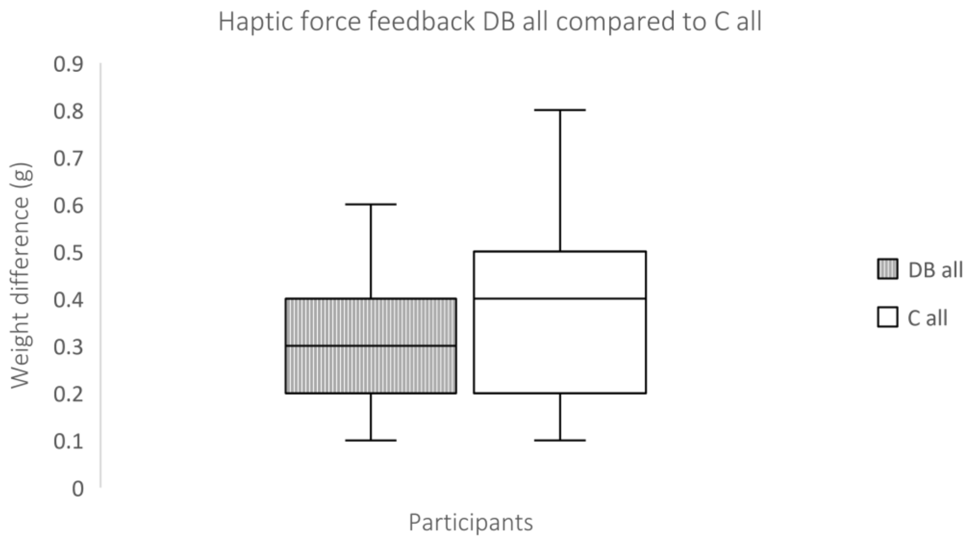

Figure 6. Haptic force feedback of people with deafblindness (DB all) compared to people without deafblindness, the control group (C all). Median C all = .3, Median DB all = .4.

Looking at the individual level, in Appendix D, Figure 22 until Figure 28 expose that in most matched pairs, there was not much difference in haptic force feedback. One trend becomes visible when looking at Appendix D: the threshold seems to be a function of comparison weight. It is visible that the thresholds were smaller in the lightest categories and bigger in the heavier categories.

When looking at Figure 7, the image becomes more clear. Error bars are calculated using the standard deviation and along with maximum and minimum values show that there is variability. The average difference scores between the participants with deafblindness and participants without deafblindness seem neglectable since the difference scores are close to zero. This was tested using a Mann-Whitney U test (see Table 9). The results show that for all locations, differences between the deafblind and control group are not significant.

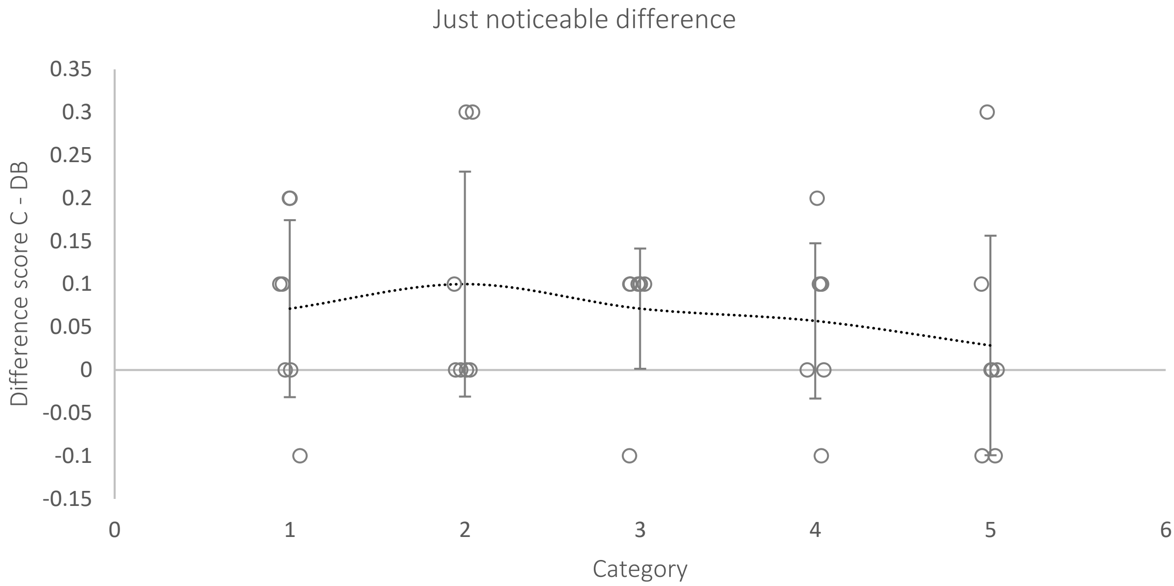

Figure 7. Difference scores of performance on JND using (scores of controls – scores of deafblind) and jittering overlapping data points using (difference score+(RAND()-0.5)/8) to visualize all the data points. The dotted line corresponds to the average trend. Category 1-5 represent 30g, 45g, 65g, 95g, and 140g, respectively.

Table 9

Statistics of tactile sensitivity on testing location. Highlighted locations are significantly different between participants with deafblindness and controls.

Location	*U*	*Z*	*p (1-tailed)*
30g	16.50	-1.09	.16
45g	13.50	-1.57	.08
65g	15.50	-1.20	.13
95g	16.00	-1.17	.16
140g	24.00	-0.70	.50

4. Discussion

The aim of the current research is to gain more insight on the haptic perception of people with deafblindness and whether their haptic perception differs from the haptic perception of people without deafblindness. Haptic perception is an important subject in communication for individuals with deafblindness: a natural focus exists on haptics since they cannot use the senses normally used for communication (i.e. vision and hearing) (Palmer & Lahtinen, 2015). Until now, it is not yet known if the haptic perception of people with deafblindness differs from the haptic perception of people without deafblindness. Our study provides the first exploration of this area.

4.1. Summary of results

This study contains three different experiments on seven people with deafblindness and their seven matched controls. Participants with deafblindness are better at aspects of passive touch, involving the spatial tactile acuity and tactile sensitivity as measured by the two-point discrimination (TPD) task and Von Frey filaments (VFf), respectively. In both tests, participants with deafblindness outperformed their matched controls. Results are convincing on average as well as on the individual level.

When analyzing the different tested body locations, it becomes clear that the index finger has a smaller TPD distance in people with deafblindness than in the control group. These results are explained by the fact that many people with deafblindness read braille with their index finger, so they are more used to distinguishing between two dots than people that do not use braille. This confirms earlier research done with blind Braille readers (Van Boven, Hamilton, Kauffman, Keenan, & Pascual-Leone, 2000).

These results contrast with results from tactile sensitivity in the index finger. When testing tactile sensitivity, the difference between the two groups in testing the index finger is smallest. This can be explained by the fact that people with deafblindness often use vibration in communication (Su et al., 2001). With vibrations, tactile sensitivity is more important than spatial tactile acuity, because it is essential that the vibration is felt, with the exact location being of less importance. In reading braille, where spatial tactile acuity is necessary, the precise location of the dots is crucial. The ability to read braille can mean that the index finger is more specialized in spatial tactile acuity and not in tactile sensitivity. Next to that, braille readers can develop callus on their fingertips (Mason & McCall, 2013), which can affect tactile sensitivity in a negative way.

Results on active touch, involving haptic force feedback as measured by just noticeable difference (JND) weights, showed a less consistent pattern. These results do not match the prior research done on this topic, where blind people were superior in discriminating weights compared to people without sensory deprivation (Grouios, Alevriadou, & Koidou, 2001). Although there was no difference in weight discrimination between groups, our results do suggest that all participants could distinguish two weights better in lighter categories. This can be explained by the Weber-Fechner law. This law states that the ability to notice the difference is determined by a proportion of the stimulus, not by the absolute difference (Purves et al., 2013).

In this experiment, people with deafblindness did not seem to have a lower haptic force feedback threshold than people with normal vision and hearing. These results can be explained by the fact that due to practical reasons, only very light weights could be used in this research. The contrast between the different weights does not seem to be enough to discover convincing differences between the various categories. Various participants stated they found the choices in the JND task difficult.

Also, in an earlier study by Grouios, Alevriadou, and Koidou (2001), on which the current experiment was based on, only congenitally blind subjects participated. In the present study, the group of participants was more diverse, which could have led to a different result.

4.2. Implications

The results conducted from passive touch confirm earlier research in specific components of tactile functioning and tactile memory of people with deafblindness (Arnold & Heiron, 2002; Janssen, Nota, Eling, & Ruijssenaars, 2007). The results also confirm that due to the plasticity of the brain, people with sensory deprivation can improve remaining senses including motor processing (Lewald, 2013; Rettenbach, Diller, & Sireteanu, 1999; Bola et al., 2016; Sadato et al., 1996). The current research adds knowledge using the fact that not only people with deaf- or blindness experience the improvement of other senses but also people with multiple sensory deficits, like people with deafblindness. It is known that active and passive touch activates the somatosensory cortex in a different way (Simões-Franklin, Whitaker, & Newell, 2010). This study proves that people with deafblindness are significantly better at passive touch than people with normal vision and hearing.

This research will contribute to the existing knowledge on the use of haptics for people with deafblindness and can be used to design new ways of communication. With these results, Bartiméus can continue working on innovative solutions to help people with deafblindness. The awareness that individuals with deafblindness are more sensitive to passive touch than others can implicate haptic communication devices that focus on passive touch, like vibration devices. As the use of vibration in (haptic) communication becomes more regular (Schorr & Okamura, 2017; Strohmeier & Hornbaek, 2017; Strasnick, Cauchard, & Landay, 2017) it is important to involve people with deafblindness in this progression, since they are more experienced in the use of their haptic sense rather than hearing and vision in communication compared to people without disabilities in hearing or vision (Heller & Schiff, 1992). Communication trough vibration could be a new and innovative way of communicating with people with deafblindness, and it could make their lives and the lives of their caregivers a lot easier.

4.3. *Limitations and future work*

All experiments with participants with deafblindness were conducted at their own homes. This choice was necessary given the problems in transportation for people with deafblindness. However, being in their own environment compared to a lab created a potentially more distracting surrounding. In future research, it would be preferable to carry out all experiments at the same, non-distracting location.

Also, communication was an issue. This can have an impact on recruitment of participants as well as the data collection in the study. With some participants, a translator was present during the experiment, in what case there might be a translation problem. A third party might interpret the questions in another way. Some researchers see the presence of a third party as a negative effect for the data collection (Low, 2006).

In the current experiment, matched samples were chosen as a control group. Obviously, it is not possible to randomly assign deafblindness to participants, so by using matched samples the differences between the two group were as small as possible, except the independent variable. However, matched samples could be affecting the results in ways that is not desirable. It is not achievable to match participants on all aspects, so perhaps the education or job differed in a way that favored one of the groups. This could have affected the obtained results.

Next to that, TPD has been criticized by researchers as a test of spatial tactile acuity due to different reasons, for example, extreme variability (Van Nes et al., 2008; Craig & Johnson, 2000). In future research, suggested is to use a grating orientation task, where participants need to distinguish the right orientation in which an angle is placed on the skin. (Craig & Johnson, 2000). This task is considered to be a better measure of spatial tactile acuity (Johnson & Phillips, 1981).

All experiments were conducted in the same order with all participants. During the experiment, some participants wanted to scratch their skin because the TPD task and VFf could itch. Scratching could make the skin more sensitive, due to serotonin release (Zhao et al., 2014). A temporary more sensitive skin could interfere with the obtained results. Counterbalancing could eliminate this interference. In future research, it could be useful to counterbalance the participants.

The results of the passive touch tests done in this experiment provide support for the hypothesis that people with deafblindness have a superior haptic perception compared to people with good vision and hearing. In the current research, participants with all different kinds of deafblindness and ages were involved. A non-homogeneous experimental group makes these results not generalizable to the population but should be seen as case studies and suggestions for further research. It would be interesting to look at the effects of time of onset of deafblindness, to see if this has an impact on passive touch. Further research is necessary to elaborate the obtained results in this study.

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Appendix A: Informed consent and Information letter (in Dutch)

Toestemmingsverklaringformulier (informed consent)

Tast bij mensen met doofblindheid

Jolijn de Heer, Universiteit van Utrecht & Bartiméus

In te vullen door de deelnemer

Ik verklaar op een voor mij duidelijke wijze te zijn ingelicht over de aard, methode, doel en belasting van het onderzoek. Ik weet dat de gegevens en resultaten van het onderzoek alleen anoniem en vertrouwelijk aan derden bekend gemaakt zullen worden. Mijn vragen zijn naar tevredenheid beantwoord. Ik begrijp dat fotomateriaal of bewerking daarvan uitsluitend voor analyse en/of wetenschappelijke presentaties zal worden gebruikt.

Ik stem geheel vrijwillig in met deelname aan dit onderzoek. Ik behoud me daarbij het recht voor om op elk moment zonder opgaaf van redenen mijn deelname aan dit onderzoek te beëindigen.

Naam deelnemer: ………………………………………………………………………..

Datum: ………………………………………………………………………..

Handtekening: ………………………………………………………………………..

In te vullen door de uitvoerende onderzoeker

Ik heb een mondelinge en schriftelijke toelichting gegeven op het onderzoek. Ik zal resterende vragen over het onderzoek naar vermogen beantwoorden. De deelnemer zal van een eventuele voortijdige beëindiging van deelname aan dit onderzoek geen nadelige gevolgen ondervinden.

Naam onderzoeker: Jolijn de Heer

Datum: ………………………………………………………………………..

Handtekening: ………………………………………………………………………..

Informatiebrief

Tast bij mensen met doofblindheid

Jolijn de Heer, Universiteit van Utrecht & Bartiméus

Bedankt voor uw interesse in het onderzoek 'tast bij mensen met doofblindheid'! Voordat u meedoet aan het onderzoek, is het belangrijk om hier meer over te weten. Neem de informatiebrief rustig door. Hebt u na deze brief nog vragen? Dan kunt u terecht bij Jolijn de Heer (jdheer@bartimeus.nl).

Het is bekend dat wanneer er een zintuig wegvalt, andere zintuigen compenseren en daardoor gevoeliger worden. Bij doven is bekend dat zij vaak een beter visueel zintuig hebben, en bij blinden is bekend dat zij vaak beter kunnen horen. Naar mensen met doofblindheid is minder onderzoek gedaan. In het huidig onderzoek wordt tast bij mensen met doofblindheid met behulp van 3 instrumenten getest.

- Allereerst wordt de 'Two Point Discrimination' gebruikt. Dit is een soort passer met twee punten, die in afstand van elkaar verzet kunnen worden. De vraag is of u per keer dat de passer op uw huid wordt gezet, 1 of 2 punten voelt.

- Daarnaast wordt de 'Von Frey Filaments' gebruikt. Dit zijn een soort haren van verschillende diktes. De dunste is ongeveer de diameter van een mensenhaar. Gevraagd wordt wanneer u de haar op uw huid voelt drukken.

De eerste twee experimenten zal ik op verschillende plekken op het lichaam uitvoeren: drie keer op de onderarm, twee keer op de hand en op de wijsvinger.

- Als laatste zal 'just noticable difference' worden getest. Hierbij zal u worden gevraagd een aantal keer het verschil aan te geven tussen twee verschillende gewichtjes.

Naast de experimenten zal u ofwel vooraf, of na afloop een korte vragenlijst (leeftijd, aantal jaren doofblind, etc.) invullen en dient er ook een toestemmingsverklaringsformulier ondertekend te worden. Dit is ter administratie van de Universiteit Utrecht. Hierin staat onder andere dat u op ieder moment tijdens het experiment mag stoppen, en hiervoor geen reden hoeft op te geven.

De resultaten van dit onderzoek zullen Bartiméus helpen in het ontwikkelen van nieuwe communicatiemiddelen op basis van trilling (zoals de TASST-sleeve of de op trilling werkende deurbel). Mocht u de eindversie van dit onderzoek graag willen ontvangen, kunt u dat aangeven bij de proefleider.

Hartelijk bedankt voor uw deelname!

Appendix B. Spatial tactile acuity

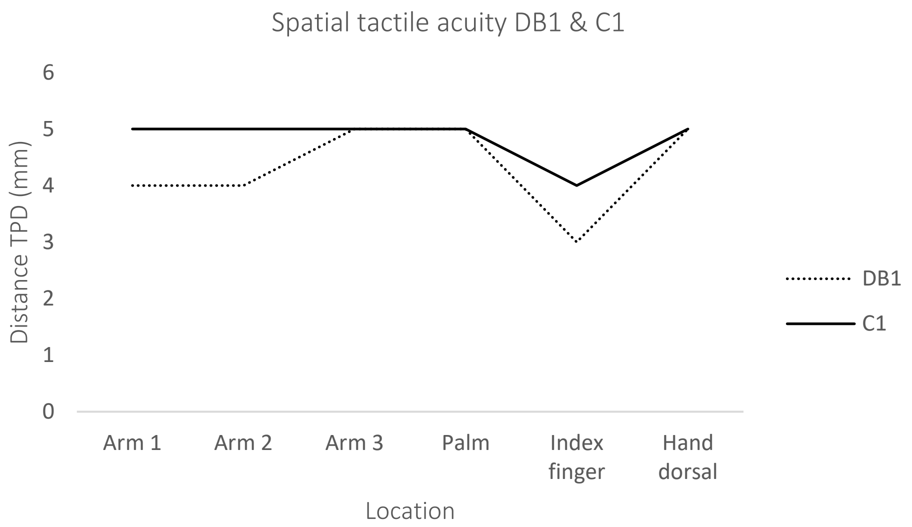

Figure 8. Spatial tactile acuity scores of DB1 compared to C1.

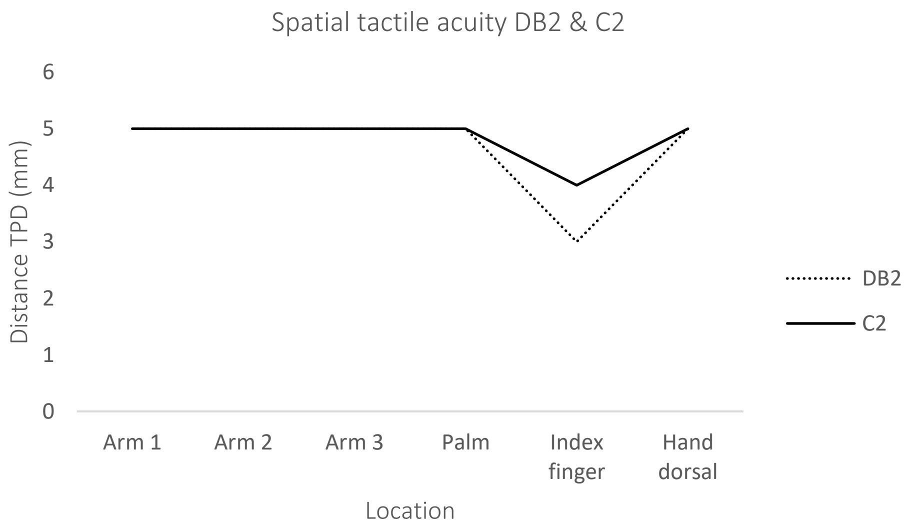

Figure 9. Spatial tactile acuity scores of DB2 compared to C2.

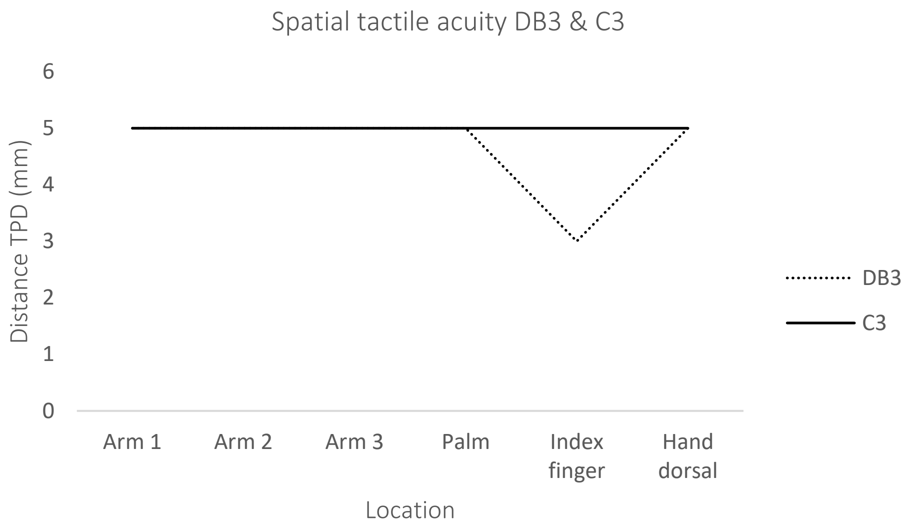

Figure 10. Spatial tactile acuity scores of DB3 compared to C3.

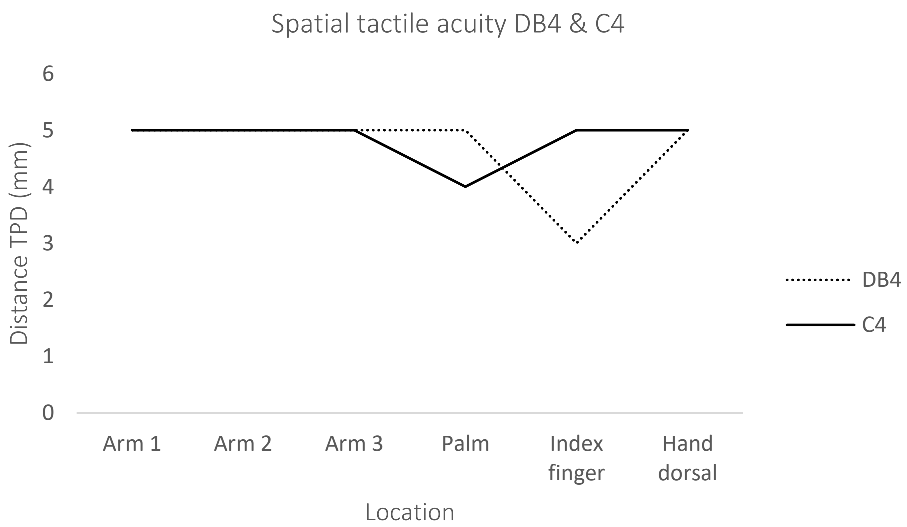

Figure 11. Spatial tactile acuity scores of DB4 compared to C4.

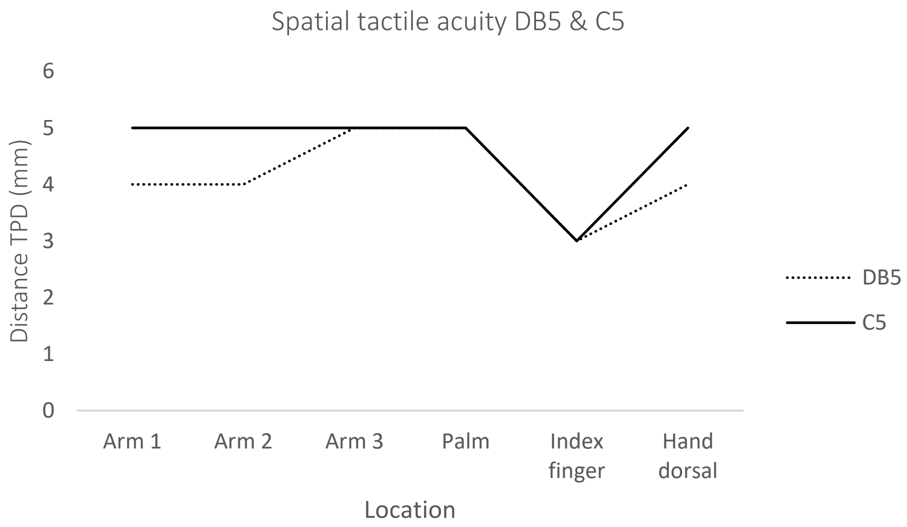

Figure 12. Spatial tactile acuity scores of DB5 compared to C5.

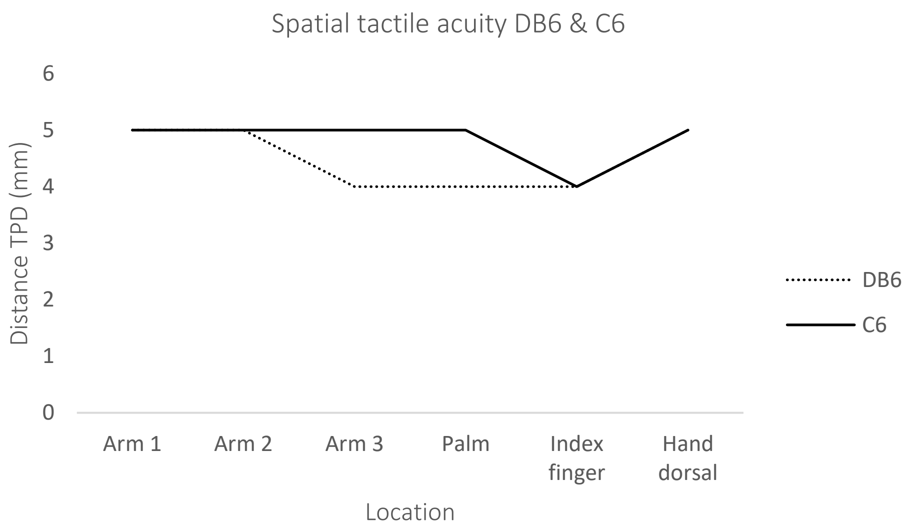

Figure 13. Spatial tactile acuity scores of DB6 compared to C6.

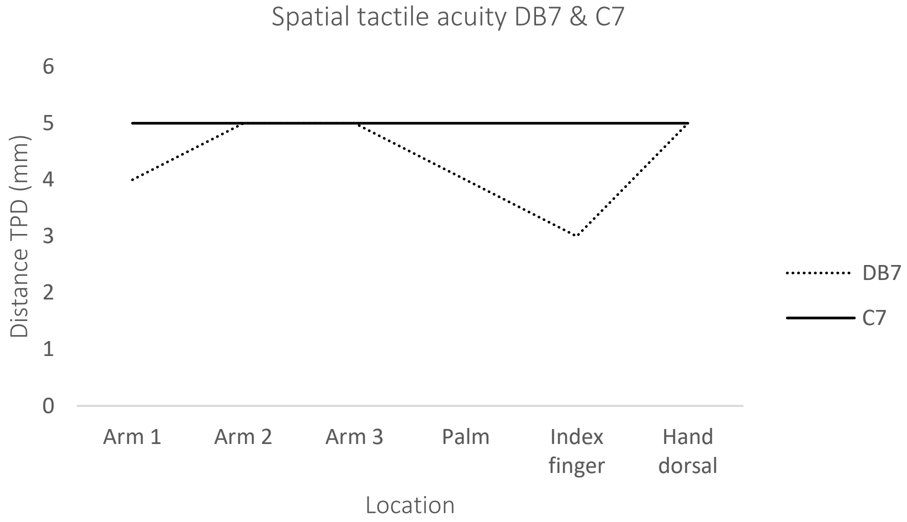

Figure 14. Spatial tactile acuity scores of DB7 compared to C7.

Appendix C. Tactile sensitivity

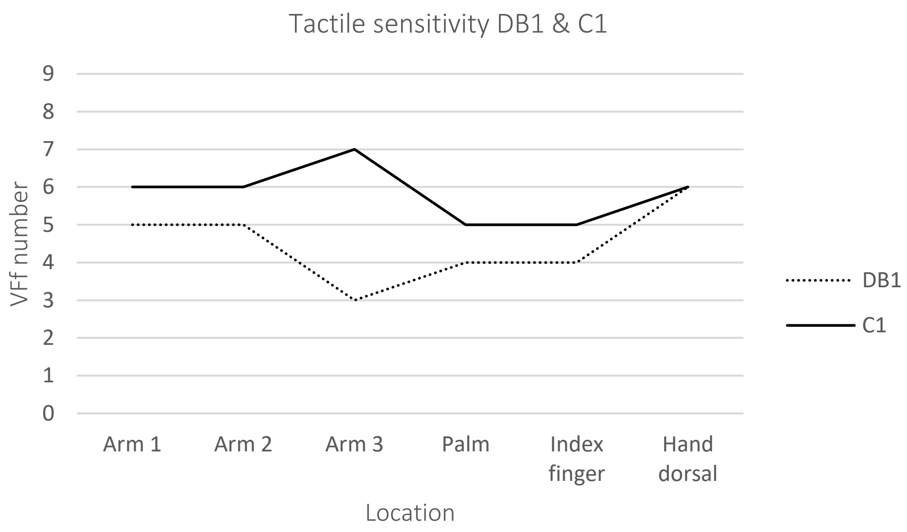

Figure 15. Tactile sensitivity scores of DB1 compared to C1.

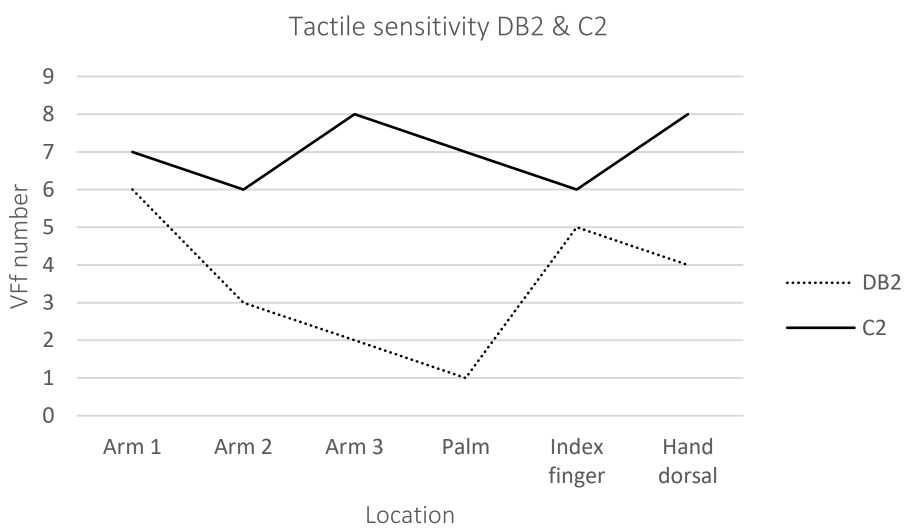

Figure 16. Tactile sensitivity scores of DB2 compared to C2.

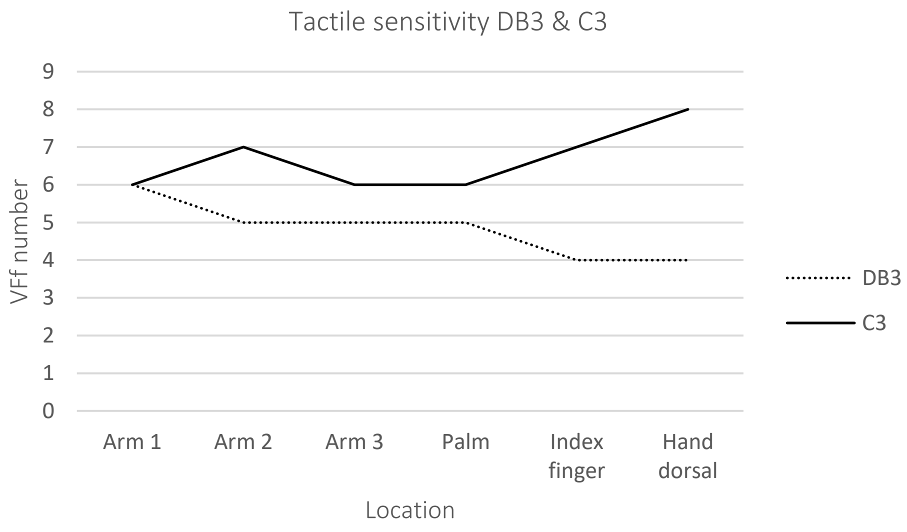

Figure 17. Tactile sensitivity scores of DB3 compared to C3.

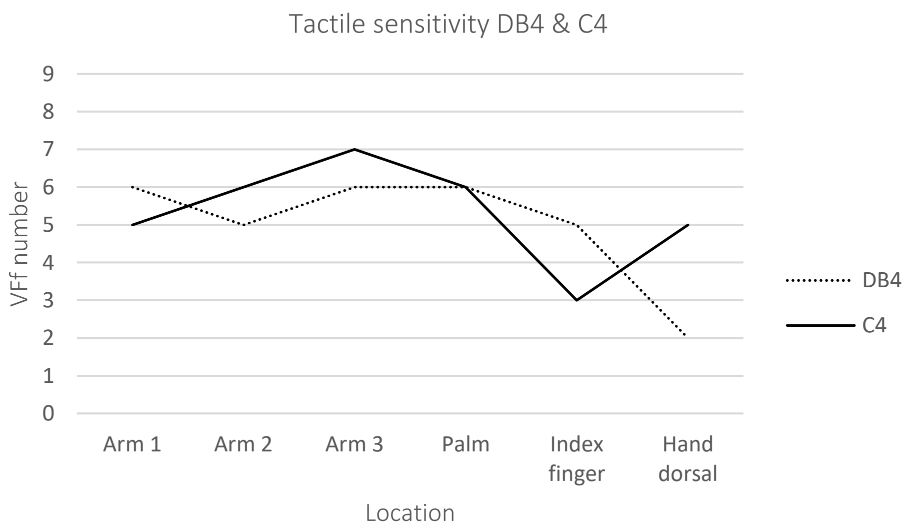

Figure 18. Tactile sensitivity scores of DB4 compared to C4.

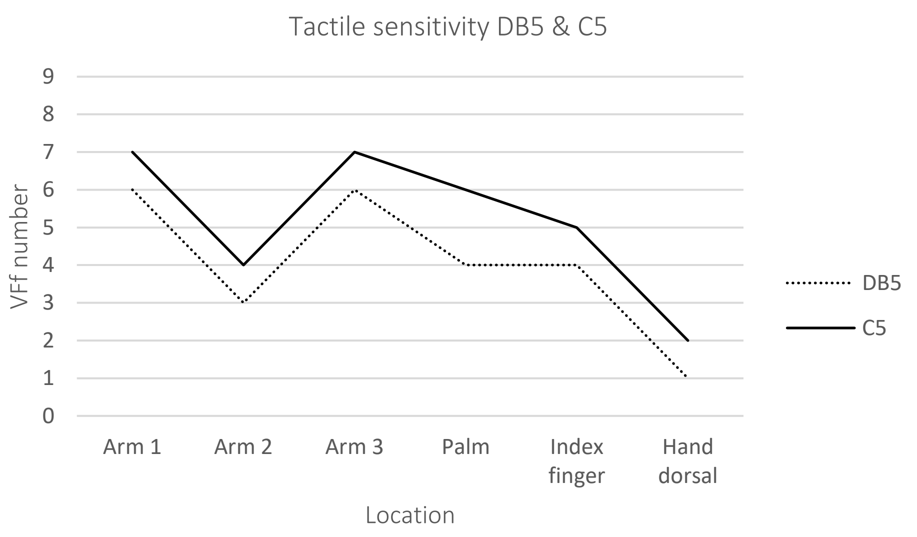

Figure 19. Tactile sensitivity scores of DB5 compared to C5.

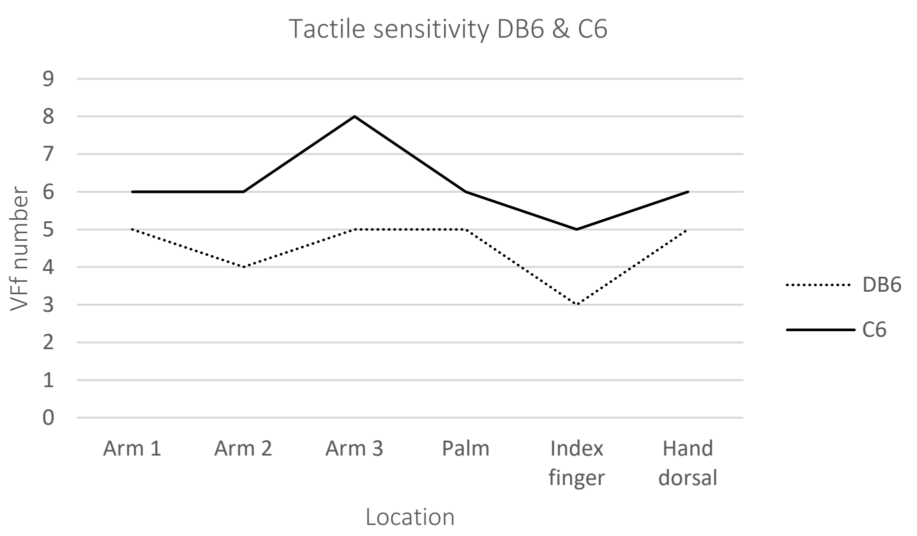

Figure 20. Tactile sensitivity scores of DB6 compared to C6.

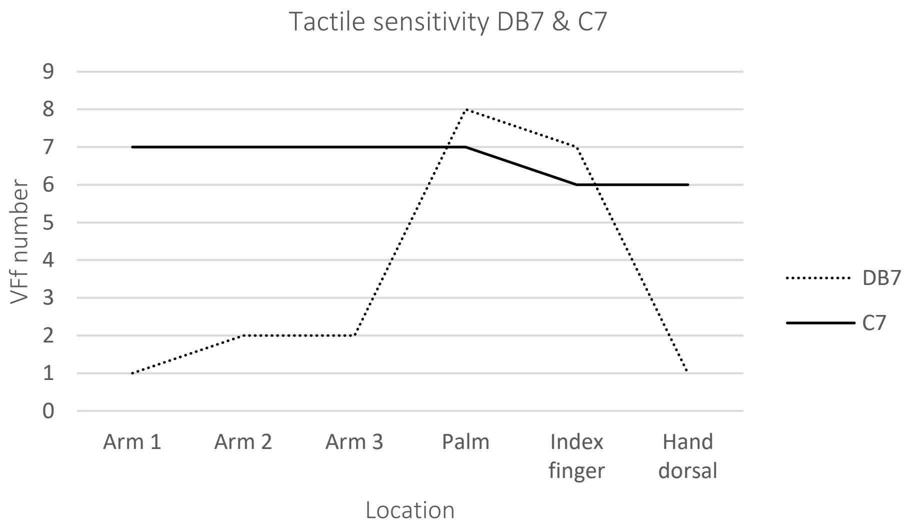

Figure 21. Tactile sensitivity scores of DB7 compared to C7.

Appendix D: Haptic force feedback

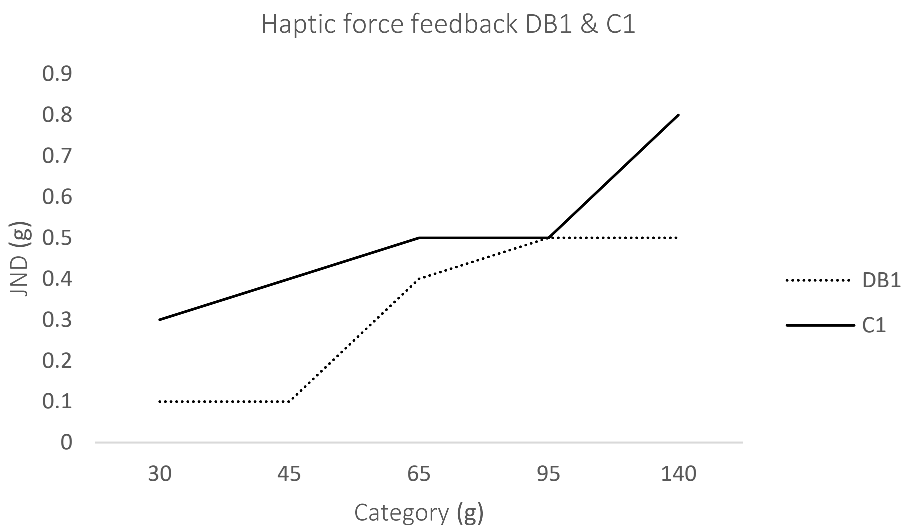

Figure 22. Haptic force feedback scores of DB1 compared to C1.

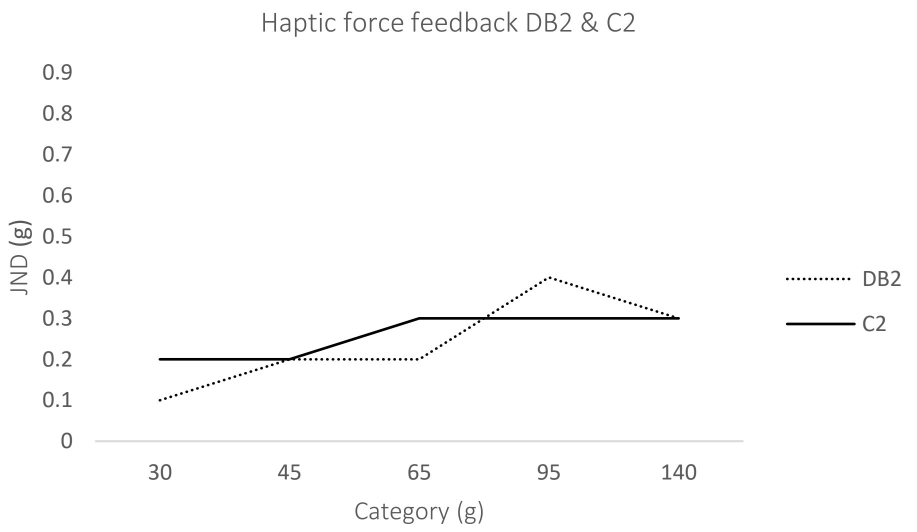

Figure 23. Haptic force feedback scores of DB2 compared to C2.

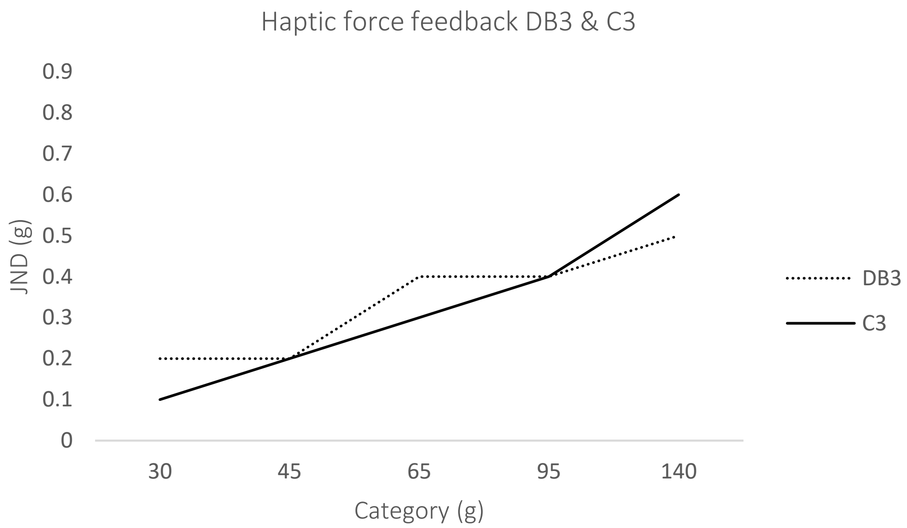

Figure 24. Haptic force feedback scores of DB3 compared to C3.

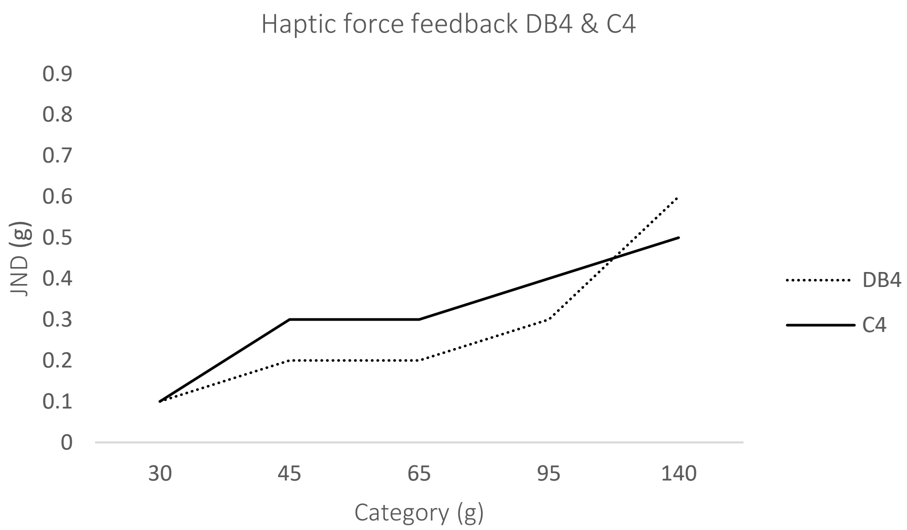

Figure 25. Haptic force feedback scores of DB4 compared to C4.

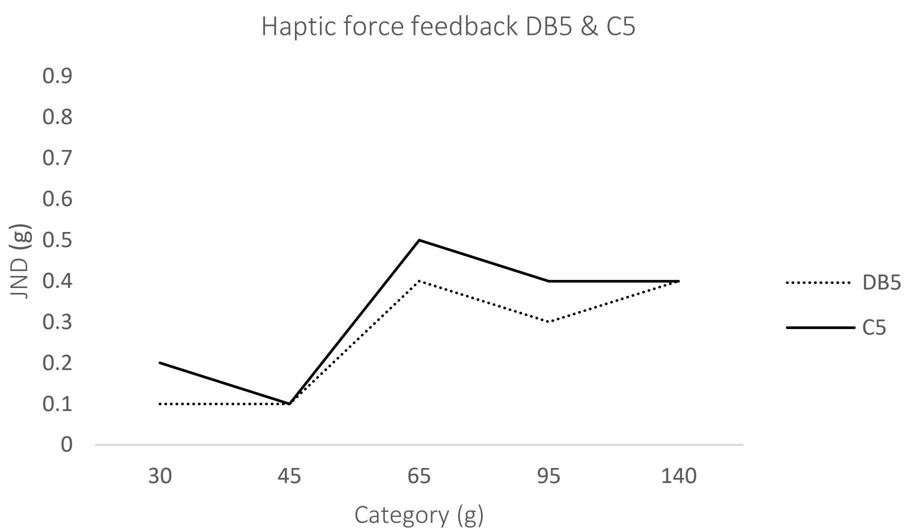

Figure 26. Haptic force feedback scores of DB5 compared to C5.

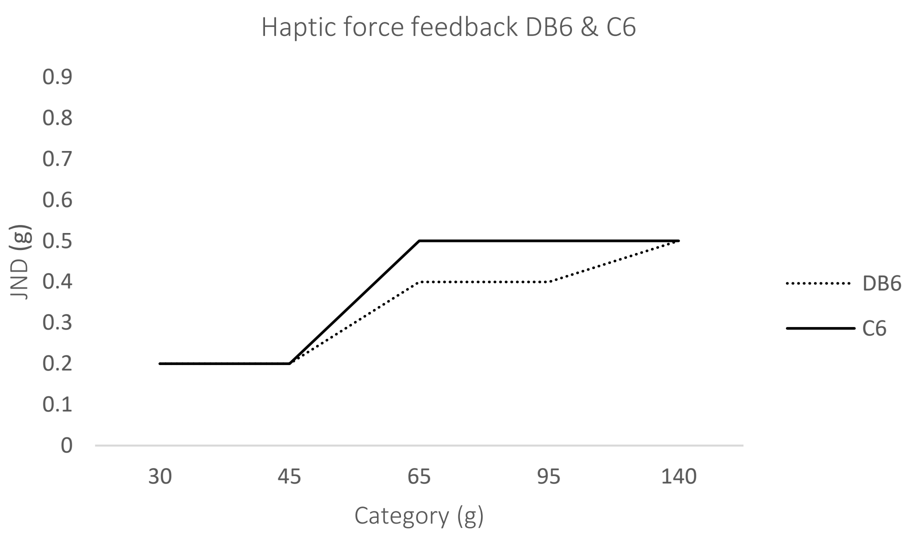

Figure 27. Haptic force feedback scores of DB6 compared to C6.

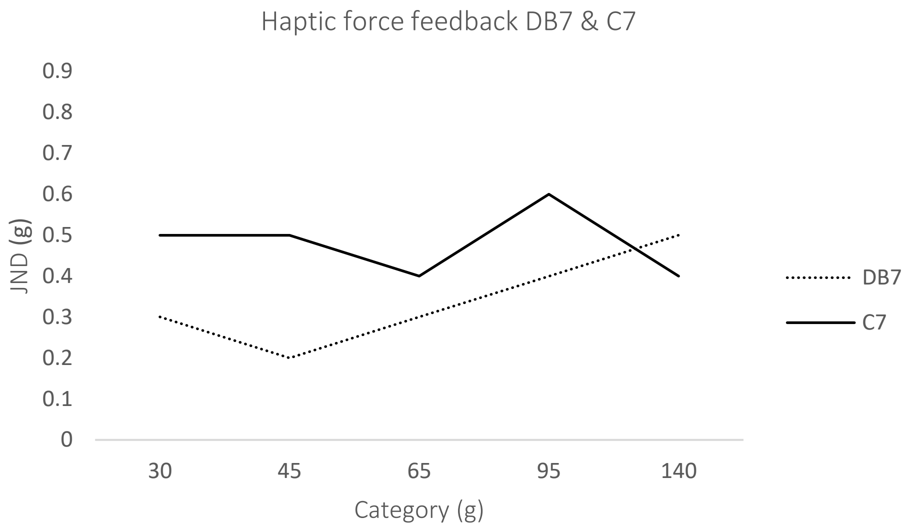

Figure 28. Haptic force feedback scores of DB7 compared to C7.