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IDENTIFICATION OF VIBROTACTILE MORSE CODE ON ABDOMEN AND WRIST

[1,2]Parivash Ranjbar, [3]Dag Stranneby, [4]Cheryl Akner-Koler, [1]Erik Borg

[1]Audiological Research Centre, University hospital at Örebro, Sweden

[2]School of Health Sciences, Örebro University, Örebro, Sweden

[3]School of Science and Technology, Örebro University, Örebro, Sweden

[4]Konstfack, University College of Arts, Crafts and Design, Stockholm Sweden

ABSTRACT

Morse code has been used as a communications system at a distance to transmit text through tone or light pulses. This comparative study aims to test and evaluate the vibrotactile identification of Morse coded signals communicating instructions for movement. The pulses were presented on abdomen and wrist among 14 males (40-85 yr) experienced in acoustic Morse code and the rate of pulses was 12 words per minute using a Vibration Motor mounted in a plastic holder. There identification results were statistically significantly better on wrist compared to abdomen. Words were identified significantly better on the wrist as compared to abdomen but the identification results of the letters were equally good in both placements. There was a negative correlation between age and the pooled identification results tested on wrist PCC r=-0.45 ($p<0.02$). The participants rank ordered the wrist, over the abdomen, as the best place for positioning the vibrator. The results support haptic/tactile interaction research in positioning and communication system. Our future plans are to apply the results to the project "Ready Ride" for instructions for horseback riding for people with deafblindness as well as activity and movement for elderly people with impaired vision and hearing.

Keywords: Deaf, Deafblindness, Haptic, Morse code, riding, tactile, vibration

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1. INTRODUCTION

Morse code has a unique pattern for each letter, including a sequence of pulses and pauses with standard duration of units (U)[1][1]. For experienced Morse operators, the interpretation process is "automatic", and does not require any conscious attention.

In the present laboratory study, we used Morse code to transmit information via skin senses as a haptic communication channel. The haptic channel for Morse communication has been evaluated by Tan, et al. [2] using two experienced and two inexperienced Morse code operators after training. The stimulus, Morse coded letters and words were presented through the auditory, motional, and vibrotactile senses at different rates: 12, 16, 20, and 24 wpm (words per minute). The study showed that when identifying single letters, three of the four participants (two experienced and one inexperienced) could perform above 95% correct at all four rates while the fourth participant, the one inexperienced, could reach the same level only for the rates R=12, and R=16 wpm.

1The two pulses are short (dit =1U) and long (dah=3U) with pauses in between each pulse(1U), letters (3U) and words (7U). The rate (R) of Morse code is expressed in terms of words per minute (wpm) with the standard length defined as 50U, where 50 corresponds to the number of units in the word Paris and the unit U = 50 ms

Haptic code transmission (not Morse code) alone or in substitution to auditory codes has been used in many studies [3-5] including physical activities or entertainment with the aim to send instructions and give feedback. In these studies a number of vibrators have been placed on particular parts of the body depending on the activity (for example on the foot when snowboarding) [3]. The vibrators send signals as pulses to give the person commands or give them immediate feedback to improve the learning of motor skills [3]. The range of information would increase if pulses with different lengths were used to code the letters and words for instruction, which can be compared to Morse code.

Haptic communication could be very useful for persons with various degrees of impaired vision and hearing as well as for situation where visual or audio interfaces are problematic or undesirable, or in situations where rapid responses are needed as e.g. presenting information about orientation or altitude to aircraft pilots. In Martin Grunwald's [6] recent review over the field of haptics he points out that practical industrial applications are gradually supporting the shift toward haptic interaction. There is, however, a great need to develop research methods that can evaluate this shift from visual and audio interfaces by designing haptic interactive systems adapted to the body.

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This present study is concerned with instruction for movement in everyday situations and leisure activities. The particular context for studying instruction for movement is in the communication between a riding instructor and a rider with deafblindness (DB). The current method for communication is through an interpreter who translates instructions to tactile sign language directly in the hands of the rider (see Fig. 1).

Fig. 1: The instructor, the tactile sign language interpreter, and the rider with DB during tactile signing.

The rider needs continuous information about her/his position in the arena, which is identified by letters [7], as well as information from the instructor (e.g., Go, Good, Turn right, Turn left, Slowly, Fast, Stop). The communication becomes tedious for the rider with DB, because tactile sign language requires that the rider stops. A riding lesson becomes less effective, because most of the time goes to communication and the rider does not receive simultaneous feedback while riding.

Ready-Ride

"Ready-Ride" is a positioning and communication system designed to support autonomous horseback riding in a riding arena for persons with DB [7]. It consists of two smart phones (sender, receiver) and a number of vibrators.

Fig. 2: Ready-Ride: two smart phones (sender and receiver) plus four vibrators in plastic holders.

Using one of the smart phones, an instructor can send information and/or feedback from a distance to the riders´ smart phone, which activates the vibrator(s) placed on different parts of the riders' body, e.g. wrist and/or back. The information is in the form of coded vibratory icons or signals, as short and long pulses which are similar to the signals used in Morse code system i.e. dit (dot) and dah (dash). The signals are produced by a DC vibration motor having the frequency about 170 Hz. The vibrator is placed in a plastic holder creating relatively large contact surface (>6 cm^2) with the skin (see section Equipment). The riders usually choose to use four of the seven vibrators. They place two vibrators on the right and

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left wrist to receive the instructions, turn right and turn left respectively, and two vibrators on the chest and back to receive the instructions like stop, or continue. Before riding lessons begin, the rider and instructor agree on what the pulses will mean, for example the vibrator on the chest means move forward. The placement of the vibrators on the different parts of the body also gives some intuitive information. For more complex instructions the rider stops and receives tactile sign language. The strength of the Ready-Ride system is the direct communication between instructor and the rider. Our preliminary observation and communication with the instructor and DB riders have shown that using the current Ready-Ride system greatly reduces the need for tactile sign language which is one of the main purposes of the system. Tactile sign language is complicated and cannot be transferred using only one or a few vibrators. The advantages for using Morse code in Ready-Ride system instead of other systems e.g. compact tactile symbols/icons are:

1. It is using letters which are used in a riding arena to mark different positions/location.
2. It is simple, based on dots, dashes and spaces which are easy to translate to vibrotactile signals.
3. It is international and opens the possibility of a linguistic communication that can be transferred through only one single vibrator.

It would be advantageous to code the first letter or the abbreviation of a word in order to simplify signals. For example, instead of the word “stop”, the letter “S” can be sent. This will also save time and extend the duration of the rechargeable battery.

Riding is important for many persons with DB and it is often used for rehabilitation [8, 9]. One reason to use Morse code is because the positions in a riding arena are labeled with 11 or 15 letters depending on the size of the arena 40mX20m or 60mX20m, respectively [7]. Persons with DB can gradually learn the whole alphabet and achieve skill for subconscious interpretation. Identification and interpretation of the codes require that the vibrations can be easily detected [10]. Detection of vibrations varies depending on the properties of the signal (e.g. frequency and amplitude), the vibrator (e.g. contact surface) and the participant (e.g., age, sex or body part) [11, 12]. The frequency of the vibrations must be in the sensitivity range of the skin, below about 700 Hz [13] and the pulses must be appropriate in duration, about 100 ms for the contact surface (about 6cm2) in Ready-Ride [13, 14]. The gap between pulses must also be appropriate in duration to avoid masking. Gap detection thresholds have been found to be at about 10 ms, which also varies depending on the amplitude of the pulses and the age of the person [15, 16]. The vibrators must be placed on a body part where the rider is sensitive [11] and be comfortable, so that s(he) can detect the signal easily and focus on the riding itself.

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The vibrations will be sensed of a person in movement, focused on riding. Movement (in this case riding) as a secondary task performance can impair detection of tactile changes on the body, which is known as the phenomenon, "tactile change blindness" [17, 18]. Therefore the pulses must be clearer than when the person is in a laboratory environment fully focused on sensing vibrations as in our experiments in present study. In the study by Tan et al. [2] the rates 12 and 16 showed optimal results and appropriate to be used in tactile identification of the Morse Code. In the present study, to have an additional margin, we chose the length 12 wpm. The rate of Morse code can be increased as the rider's experience and skills in riding and subconscious Morse code interpretation increase. The tests in this study should be regarded as a feasibility study, preceding more elaborate tests, in realistic environments.

The aim was to test and evaluate haptic identification of vibrotactile signals on the abdomen and wrist that transfer Morse coded letters and words to participants experienced in acoustic Morse.

2. METHOD

Participants:

Fourteen males between 40 and 85 years of age volunteered (no female participants) (median= 66.5). All of them had normal hearing and vision and were members of ÖSA – Örebro Radio Amateurs – who use(d) Morse code at least once a week. They were chosen in order to form a homogenous group concerning skills in Morse code identification and thereby reduce problems regarding identification results. Since our aim was only to test and evaluate the vibrotactile identification of Morse coded signals it was not necessary to test persons with DB in this initial step. In addition we could not find any person with DB who could Morse code.

Equipment:

An application was developed (using MATLAB™ software, Mathworks, 2012) to generate signals as different Morse codes and send them to a vibrator through the sound card (NVIDA high Definition Audio) in a laptop (Win7 PC, Intel® Core™ i5 CPU, M460 @ 2.35 GHz). The vibrator was a DC vibration motor with rated voltage = DC 3V, frequency = 170 Hz, body size =4x14mm / (0.16"x0.55"(DxH)), total length = 20 mm/0.8", wire length = 20mm/0.8", main material in metal and weighted 3g. The vibrator was mounted in a plastic holder having dimensions 53mmx30mmx15mm (see Fig. 3). The holder containing the battery, vibrator weighed almost 20g.

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Fig. 3: A vibrator in the plastic holder mounted on the left wrist.

Stimuli:

The stimuli were the 29 letters of the Swedish alphabet (Table 1) and the 15 most common Swedish commands used in a riding arena. The pulse lengths were: dit = 100ms, dah =3dit (300ms), space between pulses = 1dit (100ms), space between letters = 3dit (300ms) and space between two words = 7dit (700ms), as in the study by Tan et al. [2]. For example: the pattern of the Morse coded words TURN LEFT consisting of pulses (dit, dah) and three different breaks, short break between two pulses in a letter, long break between two letters and break between two words is shown in Fig. 3.

The Morse code for each letter is shown in Table 1.

Table 1: The Swedish letters and their corresponding Morse code.

A	· -	G	- - ·	M	- -	S	· · ·	Y	- · - -
B	- · · ·	H	· · · ·	N	- ·	T	-	Z	- - · ·
C	- · - ·	I	· ·	O	- - -	U	· · -	Å	· - - · -
D	- · ·	J	· - - -	P	· - - ·	V	· · · -	Ä	· - · -
E	·	K	- · -	Q	- - · -	W	· - -	Ö	- - - ·
F	· · - ·	L	· - · ·	R	· - ·	X	- · · -		

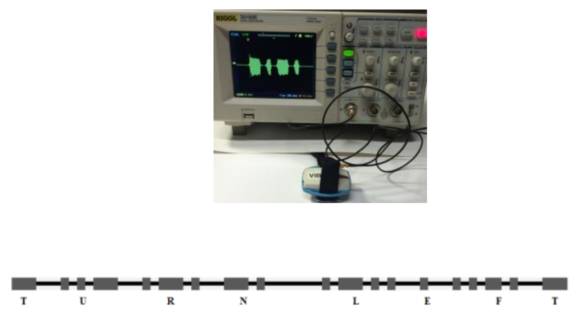

Fig. 3: The pulse pattern of Morse coded alphabet C (figure on top) and Morse coded words TURN LEFT (figure on bottom).

Two riding instructors listed 15 the most common Swedish commands for horseback riding, which are shown in the Table 2. Four of these commands (4, 5, 6 and 13), which are unique for horseback riding, the other 11 commands could be used in any situation that has to do with movement.

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Table 2: The most common words in Swedish commands in a riding arena.

1	Framåt (Forward)
2	Halt (Halt)
3	Vänd (Turn)
4	Volt (Volt)
5	Trav (Trot)
6	Rid lätt (Ride easy)
7	Rättupp (Right up)
8	Saktaav (Slow down)
9	Sittned (Sit down)
10	Vänstervarv (Left turns)
11	Högervarv (Right turns)
12	Följfyrkanten (Follow square)
13	Volt tillbaka (Volt back)
14	Framåtmarsch (Forward march)
15	Snettigenom (Diagonally through)

Tasks:

The participants performed the first stage of the tasks by perceiving the vibrations as Haptic Morse code through a vibrator held on the fingers because the fingers are very sensitive to vibration and therefore gave the participants a strong experience of the coded instructions. When the participants were familiar with the experience of haptic Morse code perception they begin the second stage in the test involving placing the vibrator on the abdomen or wrist. The fingers were not included in the second stage of the test motivated by the fact that it is not possible to have vibrators on the hand while riding. The tests on each body part were performed in the following steps:

a). Training and test of short and long pulses

The single short pulses (dit, Morse code for E) or long pulses (dah, Morse code for T) were presented five times each, and the participants were encouraged to memorize their length and distinguish the short from the long pulse. Following training, the pulses were presented in random order and the participant was asked to categorize the length of the pulses. When the participant and test leader were certain that the participant could distinguish the pulses (after three correct identifications in a row), the training was continued by presenting two combined pulses (such as "dit, dit"; "dit, dah"; "dah, dah" or "dah, dit", Morse code of I, N, M and A, respectively) five times each. After training, the letters were presented in random order and the participants were asked to identify the presented pulses as letters or the order of the pulses as, e.g., "dah, dah, dit". The training was repeated until the participant could identify the letters three times correctly.

Test of letters

Each Swedish letter (29 units, 26 Latin + Å, Ä, Ö) was presented as Morse code twice (in total 58) in random order. The participants were asked to identify the letters after they had received the whole letter code by saying the letter, e.g. "P", in a load voice or repeating the pulses in the same order as they were presented "dit, dah, dah, dit". When a letter was correctly identified, the test leader presented the next letter, otherwise each letter could be presented up to three times. The participants received feedback after they had identified the letter correctly or after the letter had been identified incorrectly for the third time. The test leader documented the participants' responses as correct or incorrect only at the first presentation (up to 3 times) for both times (maximum 6 presentations for each letter and body site). Only the response at the first presentation was used in the evaluation.

b). Test of commands

The 15 most common Swedish commands during a riding lesson in a riding arena were presented twice in random order. The participants were allowed to take notes. The word(s) were presented up to three times. The test leader documented the participants' response where only the response for the first presentation was used in the evaluation. The participants received feedback from the leader before presenting next command. The test leader collected the participants' notes as extra documentation.

3. PROCEDURE

The participants sat in a relaxed manner with a hearing protector on to prevent them from hearing any possible sound from the vibrator. The pattern of the pulses was displayed on the test leader's screen so she could see the pulses corresponding to the delivered Morse code and compare them to the pattern produced by the vibrator to make sure that the correct signal was delivered. The participants could not see the screen. The test was performed on three different parts of the body, first by placing the vibrator on the fingers and then by placing the vibrator on the abdomen or wrist. A bandage was used to place the vibrator on the abdomen and a sweatband was used to place the vibrator on the wrist.

The participants were all right handed and held the vibrator in their left hand so they could feel the vibrations on their fingers and/or palm and fingers. Their right hand was free to take notes, which is the common set up for translating Morse code. All participants were asked to record their responses on paper when identifying the letters and words. The test leader sent different signals and the participants were asked to identify the code (see section 2.4). The participants repeated the sequences of tests by placing the vibrator on their abdomen or wrist in random order. At the end of the tests, the participants indicated which of the three body sites they felt the vibrations best on. When the tests were finished, the participants were informed that

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the fingers were excluded as possible site for placing the vibrators because the fingers are needed to hold on to the reins of the horse.

The tests took less than two hours, including breaks and time for placement of the vibrator on the wrist and abdomen.

Assessment and statistical analysis

A correct response resulted in 1 point and an incorrect response resulted in 0 points. When testing commands, correct identification of commands consisting of two words resulted in 2 points, and correct identification of one of the words resulted in 1 point. Each participant could have a maximum of 58 correct responses (58 points) when identifying letters and a maximum of 50 correct responses (50 points) when identifying commands.

The data were evaluated and presented using the statistical method of percentage Mean ± Standard Error (M±SD).

The 2-way and 3-way ANOVA was used to verify the rating and the significance of the differences between placements of the vibrator. Pearson Correlation Coefficient (PCC) was used to find the correlation between the variables. All analysis were conducted using IBM SPSS Statistics version 22 [19].

4. RESULTS

All 14 participants except one (P7) completed the tests with letters. However words presented on the abdomen could not be identified by P1 and P7 could not feel the vibrations on his abdomen at all. At the beginning, when testing on the fingers, some of the participants were confused and had difficult to identify the words, but after about five presentations, especially when the words 4, 5, 6, and 13 were presented, they found that the words were riding commands and could easily identify the words. The participants were surprised over the fact that they actually understood the message received tactually. The exclusion was unknown for the participants during the testing period.

The results from tests on the fingers as initial step in the experiment were not used in the analysis and comparisons. The data and results of the tests are summarized at the Table 3.

Table 3. The statistics of the variables, number of participants, percentage values of min, max, Mean ± standard deviation (M ± SD), of identification results of the letters and words tested on abdomen and wrist.

Variable	*N*	*Min*	*Max*	*M ± SD*
Age	14	40.0	85.0	65.3±11.2
Abdomen, Letters	13	43.1	100.0	86.2±19.4
Abdomen, Words	12	3.9	100.0	69.5±31.4
Wrist, Letters	14	69.0	100.0	93.2±9.0

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Wrist, Words	14	33.3	100.0	91.9±17.2
Pooled, Letters	28	43.0	100.0	89.1±15.3
Pooled Words	27	3.9	100.0	79.7±27.9
Pooled Abdomen	25	3.9	100.0	78.2±26.7
Pooled Wrist	28	33.3	100.0	92.6±13.5

The percentage *Mean ± Standard Error (M ± SE)*, value of identification results of letters and words tested on the abdomen and wrist are visualized at the Figure 4 both as pooled and separately.

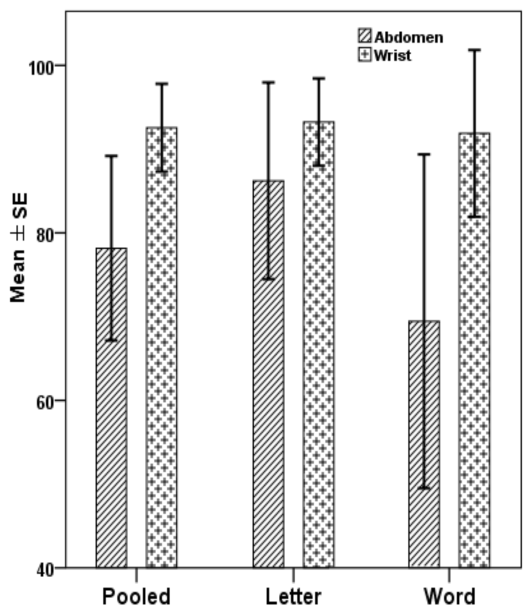

Fig. 4: The percentage M±SE, value of identification results of letters and words tested on the abdomen and wrist both as pooled and separately.

Results of abdomen vs. wrist (letters + words): The percentage M±SE of the pooled identification results of letters and words for the abdomen (78.2 ±5.3) was compared to the results of wrist (92.6±2.6). There was a statistically significant difference between the results of the abdomen and wrist [F (1, 1, 13) =12.908, p=0.001].

Results of the letters and words (abdomen + wrist): There was no statistically significant difference found [F(1, 1, 13)= 3.130, p=0.085] between the percentage M±SE of the *pooled* identification results of letters (89.1±2.9) and words (79.7±5.4).

Letters: There was no statistically significant difference found [F(1, 13)=3.114, p=0.103] between the percentage M±SE of the identification results of *letters* tested on the abdomen (8§6.2±5.4) and wrist (93.2±2.4).

Words: The *words* were statistically significantly better [F(1, 13)=9.702, p=0.01] identified on the wrist (91.9±4.6) as compared to abdomen (69.5±9.1).

Effect of age: There was a statistically significant correlation between age and the pooled identification results tested on wrist PCC r=-0.45 (p<0.02).

All participants indicated that the fingers were the best body site. Ten of the participants rank ordered the wrist better than the abdomen, and four of them rank

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ordered the abdomen and wrist as equally good.

The participants experienced each letter as a holistic pattern and melody and identified the pattern as a letter and not as short/long pulses. They could easily identify (identification scores > 90%) the letters A, D, E, M, N, R, and T. The letter H was confused with the letter S by three of participants both when testing in abdomen and wrist. When the participants were corrected by the test leader they agreed that it was H and not S. They had difficult identifying letters consisting of four or more pulses, e.g., B, C, H, J, V, X, Y, Ä, and Ö despite training and feedback when testing on fingers.

5. DISCUSSION

The results show that it is possible to identify haptic Morse code on the fingers, wrist and abdomen, which was also confirmed by the statement of one participant: "This skin perception of Morse really works". The fingers were tested first and then abdomen and wrist in random order i.e. after training. The participants rank ordered the fingers as the best body site for identifying the codes. However, it is practically impossible to have the vibrator on the fingers while riding.

The results show that the participants tended to optimize identification of these codes by relating the haptic patterns to a melody which was linked to a specific letter and word. In the International Morse Code manual: The educational method for learning both visual and audio Morse code is to concentrate on how each letter and word sounds as a whole rather than memorizing the exact number and sequence of dots and dashes [20]. This principle of wholeness is supported in research about gestalt concerning proximity [21, 22]. Possible ways to develop a haptic Morse code learning system could be through training pattern recognition of melodies. A educational method is needed to learn Morse code effectively [23]. Camille Moussette [24] research in haptic interaction brings up issues concerning recognition and discernment of haptic signals and how haptic melodies could be discerned. In the present study we are concerned with the haptic interactive user experiences of the abstract dimensions of Morse code.

The primary selection criteria included persons who could hear and see as well as had training and experience in acoustic Morse code. The number of participants could be more than 14 to do better statistical analysis. However the 14 participants were the only people we could recruit who were experienced in Morse code and willing to participate in the experiments. One could argue that it would have been more appropriate to use riders with hearing-, vision impairment and/or DB, as they are the main target group of future users. However, using participants with hearing-, vision impairment or DB would have confounded the comparison of positions (abdomen and wrist), which was the general aim of the

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study. Persons with DB were not chosen for this study for the following reasons:

-It is difficult to find and engage a large group of persons with DB. To perform statistical analysis, a large group of about 15 participants is necessary.

-All communication must go through a haptic interpreter, which is time consuming and exhausting. Communication through interpreters implies a higher risk of misinterpretation.

-Few persons with DB are experienced in Morse code.

-The test did not require that the participant had experience in riding horses.

Participants with hearing and vision, skilled in Morse code, were chosen in order to have the same approximate base line to make sure that the results were not affected additionally by confounders such as interpretation, tiredness, skills in riding or Morse code [25].

The sample then included two participants who were more than 80 years of age. They turned out to be unable to perceive haptic Morse on the abdomen. This is compatible with the known age related degradation of the cutaneous senses on various parts of the body [15].

Limitations of the haptic senses. The analysis of Tan et al. [2] shows that the speed of information processing in the cutaneous sensory system is lower than in the auditory system. This is compatible with the longer times needed for body reactions after cutaneous stimulation (moving the hand, arm, leg, etc.) than for cognitive interpretations of various acoustic signals, language, etc. Using longer pulses or gaps would weaken the holistic pattern of the codes as a melody, and participants' performance can improve with training.

Letters was easy to identify on both abdomen and wrist (86.2% and 93.2% respectively). A significant difference would have been seen in a considerably larger test population. The difference was significant when testing words i.e. between 69.4±31.4% at the abdomen and 91.9±17.2% on the wrist.

The high results of the letters on in both abdomen and wrist can be explained by the fact that the letters were short and the participants could remember the whole pattern. The words were long and most of them begin with frequently used letter (F, H, V, T, R or S), which make it difficult to guess. The words are unusual words and most used during a riding lesson. Haptic cognition/perception have higher demands on working memory [26] compared to vision which gives an overview of things where haptics relies on more sequential input. The riders are familiar with these words and while riding they can get even contextual information, for example the position in the riding arena, which can help them identify the perceived Morse code easily. More experience makes it easy to guess and

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identify even longer letters and complex words [23, 25, 27, 28].

The participants confused the letters H (four dits) and S (three dits), which can be explained by the skin's lower gap detection ability compared to hearing and by the temporal masking effect of the stimuli [29, 30]. It can also be explained by temporal numerosity discrimination where persons report less number of pulses than presented [31, 32]. The problem may partly be solved by increasing the intensity of the vibrator or decreasing the number of wpm. The vibrator can get direct contact with the skin by changing its construction, it can be changed to a larger vibrator, or it can be changed to a more broad band vibrator for example C2-Tactor which is used in other parallel studies [25].

A relatively high negative correlation between age and results was expected, and can be explained by the already high average age of the participants.

Application

Haptic Morse code can be used as an alternative method for persons with DB in leisure activity, professional situations, or any situation that requires navigation and instructions. Activities such as dance, gymnastics, swimming, work out, aerobics and theatre could be new applications for this haptic Morse code method and interactive technology. Even persons working in environments where they cannot get sufficient cues from their vision and hearing (e.g. firemen, fighter pilots, or divers) and need rapid information can get advantages of tactile information. Persons with DB can receive information from distance and thereby maintain their privacy increasing both their mobility and independence.

Future works

We plan to test and evaluate the Ready-Ride system in the field with persons with DB. Based on the experiences from the present study, we see two possible ways to apply the Morse code system using vibrotactile technology.

The first is in the traditional linguistic communication way of translating the signals of dits, dahs and spaces into letters and words. The second is in a sound/vibratory iconic way of translating the signals of dits, dahs and spaces as aesthetic rhythmic experiences that recognize a melody. For example the command "Trot" which is a paired gait, could be paired signals (- -   - -) that express the general rhythmic pattern of the horses hooves hitting the ground. By developing and using sound/vibratory icons the riding instructions become more intuitive and aesthetic rather than abstract and coded.

We believe that by combining these two ways the Ready-Ride system can offer both aesthetically composed signals through sound icons for the commands and linguistic coded signals that communicate

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individualized feedback. The two ways can complement each other.

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