Tactile Morse Code Using Locational Stimulus Identification

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Abstract—This research investigated several haptic interfaces designed to reduce mistakes in Morse code reception. Results concluded that a bimanual setup, discriminating dots/dashes by left/right location, reduced the amount of errors to only 56.6% of the errors compared to a unimanual setup that used temporal discrimination to distinguish dots and dashes.

Index Terms—Perception, Judgement, Bimanual, Communication, Vibrotactile

1 INTRODUCTION

TWO siblings, a brother and sister, were born with a neuromuscular degenerative disease that has severely impaired their hearing, vision, and ability to move. Currently, the siblings are completely deaf and nearly fully blind. The siblings have lost the neuromuscular capacity to breathe on their own. A machine pumps air through a tracheostomy tube to allow breathing, but cuts off the use of their voice boxes. The two siblings communicate via a translator that signs language several feet in front of the siblings' eyes. It is expected that their degenerative condition will worsen the sibling's eyesight to the point where sign language will be an unfeasible method of receiving communication. Currently, there is no augmented communication method or device that is suitable for the siblings. They need a communication method that allows easy discrimination of sensation for comprehension and simple methods for communicating (e.g., blinking).

Several methods have been examined for tactile communication. Braille allows a user to move their finger over raised dots that represent different characters. This can work well if the sensory and motor systems have the accuracy to perform those tasks, but can be difficult to use as a conversation method since there is no intuitive way to speak using braille. Other tactile interfaces include Tactons [1] and Haptic Icons [2] where information is encoded into sequences, rhythm, frequency, and amplitude over multiple locations. These methods are beneficial for conveying often used phrases, but are limited to a finite number of gestures.

To allow input and output without any limitation on expression, we decided to use Morse code. Morse code has most often been expressed in the audio and visual modalities, distinguishing dots and dashes temporally by relative stimulus duration (a dash is typically three times longer than a dot). Several studies have shown that Morse code can be perceived using the tactile modality [3], [4], but the auditory channel was better than tactile [5].

The bimanual locational discrimination approach presented here is hypothesized to reduce errors in Morse code reception, which is highly desirable in the case of low sensory perception. Our hypothesis is supported by hemispheric interference theory [6], [7], [8], [9], [10], [11], [12], where task interference decreases when tasks are carried out in both hemispheres of the brain. A location based stimulus discrimination method is also expected to increase the psychological refractory period (PRP), resulting in less task interference [13], [14].

This research expands on existing methods of using Morse code for communication through the tactile modality specifically for use with individuals with highly limited sensory and motor capabilities. The results presented here also have application to the other tactile communication methods discussed above.

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2 BACKGROUND

2.1 Errors in Morse Code

Highland and Fleishman [15] categorized frequent errors made in a Morse code copying task. The study included 807 Air Force radio operator trainees who had passed a 7 words per minute (wpm) code check. Subjects performed several Morse code tests in one day. The tests consisted of copying an audible Morse code signal received at 9 wpm. Operators who did not achieve 80% accuracy or did not perform a Morse code test at least 1.5 times per day were discarded from the study, leaving 299 subjects. Errors in copying code were classified into four categories, what Highland and Fleishman refer to as the four "Factors": dot estimation, dash estimation, internal error, and flipping error. These categories were present in 85.8% of all errors made. Highland and Fleishman's errors can be further simplified into two categorical types: counting errors and identification errors. Counting errors (dot/dash estimation) occurred when the amount of dots or dashes was misinterpreted. Identification errors occurred when dots were mistaken as dashes and vise versa.

2.2 The Neurological Processing of Morse Code

Lara Schlaffke found that Morse code is a two-task process [16]. The first task is a perception process of identifying stimulus length (deciding whether a stimulus is labeled as a dot or a dash). Once this stimulus has been successfully identified, a lexico-semantic analysis is performed to identify words from non-word elements.

2.3 Stimulus Discrimination between Hemispheres

Representing Morse code elements with a tactile stimulus adds an extra dimension to the design space that can be explored as a factor to potentially improve tactile temporal numerosity judgments. Bradshaw et al. [6] concluded that an intermanual condition leads to faster completion of judgment tasks than an intramanual condition. This implies that the processing load being shared between two hemispheres is more efficient than information processed in just one hemisphere. Craig [7] concluded the same where subjects were presented with tactile patterns in rapid succession, either inter- or intra-manually, noting that the intermanual advantage disappeared after a 400 ms delay between stimuli.

The hemispheric models of Friedman et al. [8], [9], [10] and Iida et al. [11] state that the left and right hemispheres have a finite amount of processing resource pools. Interference occurs when multiple tasks are using the same processing resource pool within a hemisphere. This model is further supported by Kinsbourne and Cook's experiment [12] where subjects were tasked to balance a wooden dowel on their left and right index fingers while speaking. Their results showed a decreased performance of dowel balancing on the right index finger when subjects were asked to repeat a verbalized sentence. Kinsbourne and Cook postulated that this decline of performance when a verbal task was introduced was due to interference occurring in the left hemisphere. Right sided motor control and verbalization tasks have cortical centers in the left hemisphere. They suggested that interference is a function of the distance between cortical spaces, with more interference occurring when this distance is shorter, which also increases the chance of resource sharing.

2.4 Tactile Enumeration

Verlaers et al. [17] concluded from their experiments that haptic subitizing haptic geometrical patterns can take place. Subitizing is most accurate for a few items (<3) and fast enumeration (<100 ms/item) where counting is better suited for tasks of many items and slower enumeration (>200 ms/item). Subjects used their index finger to scan tactile bumps on a flat surface, similar to braille, in geometric patterns to test if subjects were capable of performing the enumeration process of counting faster when the dots were organized in configured patterns (e.g., triangle, squares) versus being presented in a straight line. It was found that configured patterns lead to faster enumeration, which suggests subitizing took place. A tactile pattern created by vibration motors could allow more accurate enumeration in Morse code, potentially reducing errors of dot/dash estimation, shown in Highland's study [15] to represent 44.6% of Morse code errors.

2.5 The Psychological Refractory Period

Palshar and O'Brian [13] investigated if Welford's psychological refractory period (the PRP effect) [14] attributes a significant difference of performance in rapid stimulus identification tasks. The PRP effect comes from a bottlenecking of response tasks, where critical information from the first task introduced must be processed before attending the second task. Any overlapping critical processing task leads to interference occurring in the second task. Palshar and O'Brian mention in their literature review that the PRP effect occurred for cases where response selection occurred [13].

Palshar and O'Brian [13] conducted five stimulus identification experiments where tasks were suspected to be processed either completely in the left or right hemisphere. Their experiments consisted of a verbal task, a visual task (where one eye was covered), or a left/right motor task. For example, in one experiment, subjects verbally identified a pitch as "high" or "low" (a left hemisphere controlled operation). Then after a varied amount of stimulus asynchrony, a second task was introduced to identify the position of a disk, where the left eye was covered and the left hand entered the answer, or vice versa for the right side. The summary conclusion for all of Palshar's experiments is that the second ordered task yielded lower accuracy and longer response times, whereas using either just one hemisphere or both hemispheres to process a task was insignificant to accuracy and response time. This result suggests that the PRP effect supersedes the benefit that utilizing both hemispheres provides [13].

2.6 Time Shrinking

Erp and Spapé [18] found that time shrinking occurs for rapid numerocity tasks when stimuli with different temporal lengths occur in the tactile modality. The time shrinking phenomenon occurs when stimuli are presented in a rhythmic pattern, where a longer stimulus is followed by a shorter stimulus results in the shorter stimulus being underestimated. Time shrinking is expected to occur in traditional Morse code whenever a dot (short stimulus) follows a dash (longer stimulus), leading to potential inconsistency in stimulus identification and therefor higher error in Morse code reception. Location based stimulus discrimination would remove any existence of the time shrinking effect in Morse code.

3 Experimental Design

The goal of this experiment is to understand how best to display Morse code haptically. We aim to reduce the number of errors and/or to increase the speed at which the Morse code can be understandably delivered.

3.1 Experiment Overview

Four haptic setups were tested in this experiment as shown in Figure 1. The three changes between the setups {shown as (a), (b), and (c) in Figure 1} focus on evaluating: (a) the effectiveness of a bimanual Morse code representation, (b) how to equalize the duration of dots and dashes to reduce transmission time, and (c) how to reduce counting errors of successively similar elements.

Setup 1 uses time based dot/dash discrimination, just like visual or auditory Morse code does. The dots and dashes are both applied on the left arm. A recent study has shown that there is no difference in the tactile perception of vibration patterns on the left and right arms [19]. However, other studies have indicated that the left hand can discriminate vibrational patterns better than the right under active tasks [20], which would suggest that only using the right hand would have worse performance than the left.

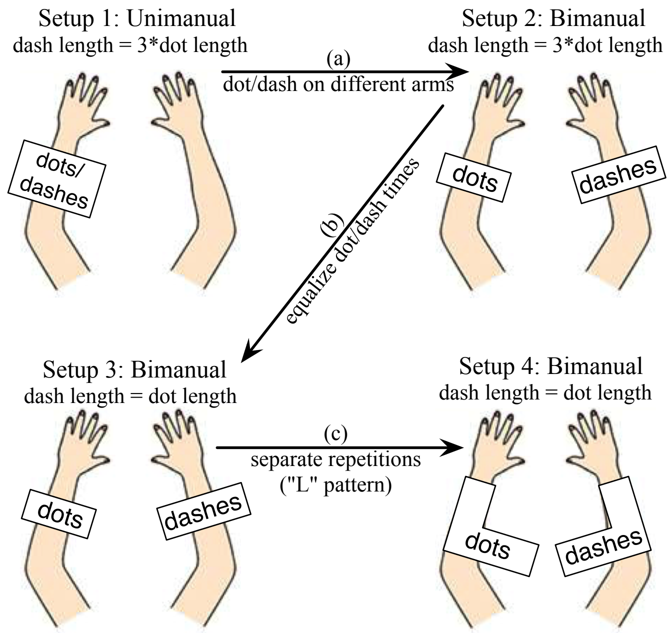

Fig. 1. The four haptic setups. Setup 1 uses time based dot/dash discrimination (unimanual). Setup 2 uses location based dot/dash discrimination to test significance in hemispherical interference/PRP effect. Setup 3 sets dash duration to dot duration to reduce Morse code transmission time. Setup 4 uses an “L” shaped motor configuration to potentially reduce dot/dash estimation error (counting errors).

Setups 2, 3 and 4 evaluate if bimanual locational discrimination of stimuli reduces Morse code errors. By processing stimuli bimanually, it is expected that each stimulus will have its sensory information processed within each hemisphere. Studies exploring hemispherical interference support the hypothesis that this will decrease Morse code errors [6], [7], [8], [9], [10], [11], [12]. When Morse code stimuli are distinguished temporally, there is a waiting period before enough information is available to determine whether a stimulus is a dot or a dash. This waiting period is the temporal length of a dot. If the stimulus continues after one dot length, the stimulus can be identified as a dash, else it is a dot. However, if location is used to discern a dot from a dash, there is no such waiting period. The stimulus can be identified as a dot or dash immediately after being presented. Avoiding this judgment lag is expected to reduce the PRP effect between stimulus identification and the lexico-semantic analysis of Morse code characters [13], [14], [15].

Setup 3 sets dashes to be the same length as dots, which reduces transmission time. This setup could potentially improve performance by eliminating the possibility of time shrinking, which Erp and Spapé [18] suggest would cause underestimating a dot if it came after a dash.

Setup 4 uses a counting “L” shape pattern (see Figure 2) to address Morse code counting errors, which make up 44.6% of all errors in Highland and Fleishman’s study [15]. Successively similar elements within a character increase the amount of motors triggered (up to a maximum of three motors). It is expected that counting will be reinforced when accompanied by a shift in motor intensity. Verlaer et al.’s study [17] shows that simple geometric patterns increase enumeration task performance.

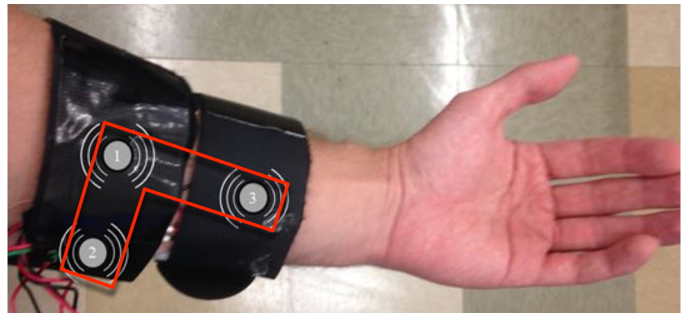

Fig. 2. Motor arrangement for haptic setup 4. Motors are actuated based on numeric labeling from smallest to largest.

3.2 Participants

Eight subjects, two females, two left handed and one self-reported as ambidextrous, all between 20-30 years of age, participated. All subjects were healthy with no conditions that hindered their ability to sense stimuli in their forearms. None of the subjects had any prior experience with Morse code. Novices of Morse code were chosen as subjects for this experiment rather than experienced individuals since they would have been expected to have a higher performance for Setup 1 (unimanual) compared to the other setups. This bias was avoided by using subjects that were equally inexperienced on all setups.

Each participant read and signed a consent form before the experiment following a protocol approved by the University of South Florida’s Institutional Review Board.

3.3 Experimental Setup

The dots and dashes were presented using 10 mm coin type vibration motors vibrating at 216 ± 50 Hz with a magnitude of 0.9 G. The lag between sending a signal and an output vibration is approximately 40 ms, however this does not impact the perception since this is similar for starting and stopping the motor. The timing was controlled from a computer connected to an Arduino via USB.

3.4 Farnsworth Spacing

Farnsworth spacing is a method of teaching Morse code where character elements and inter-element spacing have a high wpm, but characters and word spaces are longer than usual [21]. Allan [22] found that novices have higher performance in Morse code reception when learning Morse code with a pattern recognition method, such as Farnsworth spacing, relative to novices who used an analytical learning approach. A Farnsworth spacing scheme also allows for a fair comparison between Setup 1 (unimanual) and Setup 2 (bimanual), as difficulty scaling does not alter stimulus identification, since temporal discrimination identifies different stimuli based on relative duration. Figure 3 compares the traditional time scheme to Farnsworth spacing.

3.5 Overview of Testing Program

The order in which the haptic setups were tested was randomized for each subject. The haptic setups were balanced across all subjects so that each setup appeared first twice and second twice. This was done to minimize the effects of a learning curve and prevent a biased advantage or disadvantage if it occurred earlier in the experiment

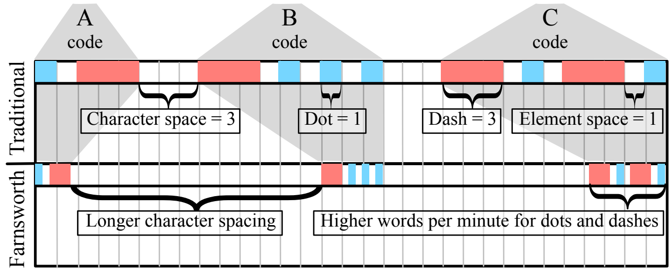

Fig. 3. Comparison between traditional and Farnsworth spacing. Changing the Farnsworth spacing reduces element and inter-element time while increasing time between characters. Farnsworth spacing can be easier to learn for novices.

than another setup. Subjects were acoustically shielded with headphones playing falling rain to ensure that acoustic identification of stimulus played no role in the experiment.

Subjects were given a copy of a sheet with the 12 Morse code characters used here to study before the experiment. Subjects had access to three documents throughout the entirety of the experiment:

1) An image of the four haptic setups and a brief description of how they worked.
2) A sheet with the 12 characters without their respective Morse code under them.
3) A gridded sheet of paper where a subject could write down answers after receiving Morse code.

Subjects took a competency test before data collection to ensure they knew all 12 of the Morse characters with at least 80% accuracy. Subjects then completed a practice test with a Farnsworth spacing of three seconds between characters, where the subject could become accustomed to interpreting three Morse code characters in a row.

The subjects then identified 144 combinations of three characters displayed to them. This consisted of three bouts of 12 combinations presented in a random order for each of the four setups. The subjects wrote their answers on a gridded sheet of paper to transcribe the characters as they perceived them. Subjects were not allowed to write down the elements that represented Morse code (e.g., – – – • •) because this would allow them to focus on stimuli reception and identification, then have indefinite time to do Morse code translation to English text (lexico-semantic analysis).

3.6 Chosen Morse Code Characters

Morse code characters were chosen in such a way to provide a fairly equal representation of Highland and Fleishman's four categories of the most common Morse code errors [21]. Figure 4 shows the twelve characters selected to be used in the experiment. The following is the list of the categorized error pairs present in the study:

1) Dash Estimation: (J:W),(W:J),(1:J),(J:1),(1:W),(W:1)
2) Dot Estimation: (H:S), (S:H),(5:H),(H:5),(5:S),(S:5)
3) Internal Error: (V:U), (V:U), (8:7), (7:8)
4) End Element Error: (V:H),(H:V),(5:4),(4:5)

3.7 Morse Code Speed

Boldt et al. [23] measured the just noticeable temporal difference for numerocity tasks to be 50-120 ms for 50%-90% accuracy. Morse code characters were chosen to be sent at

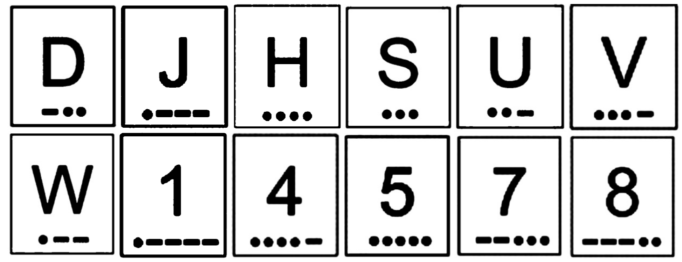

Fig. 4. The twelve selected Morse code characters tested.

13 wpm, making a single time element equal to 92 ms. A 13 wpm speed was chosen so that Morse code identification was fairly challenging to perform so that perception mistakes could be studied.

4 Results

4.1 Setup Performance Overview

A two-way ANOVA with repeated measures was performed in SPSS with error as the dependent variable and independent variables of setup (four factors) and repetition (each setup was repeated three times). There was a statistically significant difference between the setups ($F(3, 21) = 5.062, p < 0.05$). A post hoc test with Bonferroni correction was conducted among the setups, shown in Figure 5, which revealed a statistically significant difference between Setup 1 and Setup 2, where Setup 2 showed 56.6% the number of errors that Setup 1 had. Setup 3 and Setup 4 had no statistically significant difference compared to any of the other setups. There was not a statistically significant difference between the three repeated trials for each setup.

A separate repeated measures ANOVA was performed with associated post hoc test to examine the order in which the setups were taken. This analysis showed a statistically significant increase in the Morse code errors for the first setup displayed ($F(3, 21) = 3.898$, $p < 0.023$). However, the experimental design balanced the orders of which setup was displayed first and second, ensuring each haptic setup showed up in the first and second order two times throughout all subjects. Although the first setup shown to a subject performs worse on average by 19.5% compared to the best order, no setup is biased to perform better than another setup due to equal representation of being presented first throughout the experiment.

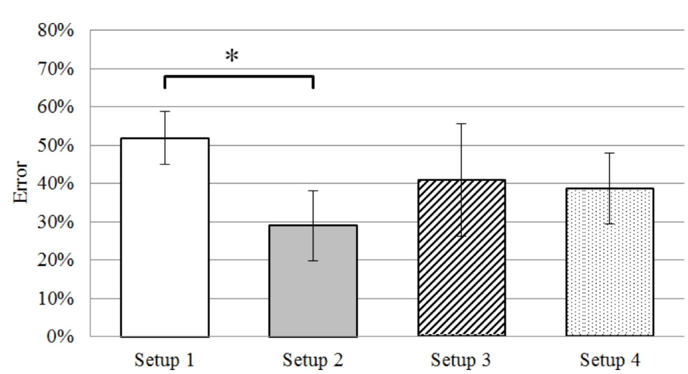

Fig. 5. The twelve selected Morse code characters tested. Error bars show the 95% confidence intervals with statistically significant difference shown by an *.

4.2 Highland and Fleishman's Categorical Errors

There were no statistically significant differences between any of the haptic setups for Highland and Fleishman's categorized Morse code errors. Table 1 lists error occurrences for each categorical error among the four setups along with Highland and Fleishman's results. Table 2 lists the amount of categorical error pairs among all possible error pairs for the current study and Highland and Fleishman's study.

Categorized character error pairs represented 15.2% (20 error pairs out of 132 total error pairs available) and made up an average of 39.1% of all errors between the four haptic setups in the experiment. In Highland and Fleishman's study, categorized errors represented 5.5% (69 error pairs out of 1260 total error pairs available) and made up 85.8% of all errors made. In this study, categorized error pairs were 2.6 times (39.1%/15.2%) more likely to result in an error than non-categorized pairs while in Highland and Fleishman's study, a categorized pair was 15.7 times (85.8%/5.47%) more likely to result in an error relative to non-categorized pairs. Subjects in Highland and Fleishman's study were 6.1 times (15.7/2.6) more likely to make a categorical error than the subjects in this study instead of a non-categorized error. These differences are likely due to the Morse code skill level of the participants.

5 Discussion

This research demonstrated that representing Morse code with a bimanual setup reduces errors made by approximately half compared to a unimanual represention. For the sensorimotor-impaired individuals who will be receiving Morse code as an alternative communication method, a bimanual haptic setup will allow fewer errors in receiving communication. This finding is also significant for complicated haptic interfaces with multiple, quickly successive feeds of tactile stimuli. Such interfaces that meet this criterion are vibrotactile body interfaces for alerting blind individuals of obstacles [24]. The need to design complex full body haptic interfaces might arise as an extra element of immersion in conjunction with a VR platform, or as a means of avoiding obstacles for persons who are visually impaired.

TABLE 1
Percent contribution of the four categorized errors within each setup. Highland and Fleishman's errors in his study are also shown.

Error Category		Setup 1	Setup 2	Setup 3	Setup 4	Highland & Fleishman
Categorized Error		30.7%	42.0%	37.7%	36.0%	85.8%
Sub categories of error	*Dot Estimation*	*11.4%*	*19.2%*	*13.3%*	*12.9%*	*36.2%*
	Dash Estimation	*9.8%*	*12.0%*	*16.0%*	*12.9%*	*8.4%*
	Internal Error	*7.2%*	*10.2%*	*8.0%*	*8.9%*	*30.1%*
	End Element Error	*0.6%*	*0.4%*	*1.3%*	*11.1%*	*11.1%*
Other Error		69.3%	58.0%	62.3%	64.0%	14.2%

TABLE 2
Frequency of error pairs within all possible error pair combinations.

Error Category	Current Study	Highland and Fleishman's Study
Dot Estimation	6 (4.5%)	11 (0.9%)
Dash Estimation	6 (4.5%)	18 (1.4%)
Internal Error	4 (3.0%)	26 (2.1%)
End-Element Error	4 (3.0%)	14 (1.11%)
Total Error Pairs	132 (100%)	1,260 (100%)

5.1 The PRP Effect vs. Hemispherical Interference

The statistically significant difference between haptic setups 1 and 2 is likely due to the PRP effect that is present when a stimulus duration is the identifier for dots and dashes. The PRP effect exists since it is impossible to identify a dot or dash until the full duration of a dot has been represented when using temporal discrimination as a stimulus. If a stimulus ends, then it can be concluded that the stimulus was a dot; if the duration of stimulus continues, it can be classified as a dash. The PRP effect is less likely to occur when the stimulus is discriminated by location, as identification can occur instantaneously whenever the stimulus is introduced. The delay in stimulus identification for temporal discrimination leads to more frequent overlapping of three tasks: stimulus reception attention, stimulus identification, and Morse code translation to English characters (lexico-semantic analysis).

Future experiments that isolate the PRP effect and hemispherical interference theory are required to understand which effect results in the statistically significant difference between Setup 1 and Setup 2. Palshar and O'Brian [14] concluded that hemispheric processing has no effect for PRP tasks. Since this experiment fits the description of Welford's PRP effect, it appears that the hemispherical inference played no role in Morse code identification performance.

5.2 Highland and Fleishman's Categorical Errors

Subjects in Highland and Fleishman's study were approximately six times more likely to make a categorical error than a non-categorical error compared to the subjects in this study. Highland and Fleishman had to discard a considerable amount of subjects from their study, as they discarded code checks that fell below 80% accuracy since they deemed these code checks to be an indication of a subject getting lost in the code and making random errors. The subjects in our study perceived Morse code characters an average of 60% of the time among all haptic setups. Subjects had a 71% accuracy using Setup 2, the best performing method. It is expected that the skill level of the subjects in this study lead to getting lost in the code, meaning interference between the tasks of stimuli identification and semantic analysis took place more often than performing one of highlands categorized errors that would be due to a nuanced error in stimulus perception.

Having more subjects and subjects that are experienced in Morse code could allow for more specific insights regarding mistakes made for all haptic setups tested. However, to ensure a fair comparison between using locational bimanual stimuli discrimination and temporal stimuli discrimination, it is necessary to either use novices as test subjects or to train users to become experts on each of these four setups, which would take a significant investment from each participant. In addition, our goal is to help two individuals with sensory impairments that are not experts.

6 Future Work

6.1 Hemispheric Interference in a Morse Code Task

A follow up experiment is required to confirm that the statistically significant difference between Setup 1 and Setup 2 is due to the judgment buffer effect and not hemispheric interference. The experimental design for such an experiment will compare two haptic setups: one setup being the same as Setup 1 in this study, where stimulus is identified with stimulus duration, and the other setup will also be unimanual, but use stimulus location to distinguish dots and dashes, where dots will be represented on the forearm and dashes will be represented on the bicep. If it is found that Setup 1 is statistically significantly more likely to make an error, it can be concluded that a judgment buffer does indeed exist.

6.2 Does PRP Effect Occur for a Morse Code Task

The presence of a greater PRP effect for the unimanual setup makes it very difficult to validate the theory of separate hemispheres having a finite resource pool with these experimental results, as task interference occurs in higher quantities for the unimanual setup in relation to the bimanual setup. A better measure of interference would be to compare a unimanual setup attached to the left arm with that of a unimanual setup on the right arm. The right arm setup would have all information processed in the right hemisphere, while the left arm setup processes stimulus in the right hemisphere and performs lexico-semantic analysis in the left hemisphere.

7 Conclusion

This study showed that using stimuli that are identified with bimanually opposite locations results in statistically significantly lower errors in Morse code perception than using stimulus duration in a unimanual condition. Results from the subjects did not follow the common Morse code error categories from Highland and Fleishman, meaning that error mistakes may have been caused by a different perception mechanism. It is suspected that this interference can be either from hemispheric interference theory, where tasks are capable of being processed easier when overlapping due to information being synthesized in separate hemispheres, or due to the PRP effect, where the inherent delay in stimulus identification when using stimulus duration as a stimuli identifier results in more interference. To be certain if the difference between setups 1 and 2 is due to either hemispheric interference or a judgment buffer, there needs to be a follow up study that tests haptic setups that separate these two phenomena.

References

[1] Brewster, S. A., and Brown, L. M. “Non-visual information display using tactons”. In CHI’04 extended abstracts on Human factors in computing systems (pp. 787-788), ACM, 2004.

[2] Ternes, D., and MacLean, K. “Designing large sets of haptic icons with rhythm. Haptics: perception, devices and scenarios”, 199-208, 2008.

[3] Sherrick, C. E. The art of tactile communication. American Psychologist, 30(3), 353, 1975.

[4] Heller, M. A., Nesbitt, K. D., Scrofano, D. K., and Daniel, D. Tactual recognition of embossed Morse code, letters, and braille. Bulletin of the Psychonomic Society, 28(1), 11-13, 1990.

[5] Tan, H. Z., Durlach, N. I., Rabinowitz, W. M., Reed, C. M., and Santos, J. R. Reception of Morse code through motional, vibrotactile, and auditory stimulation. Attention, Perception, & Psychophysics, 59(7), 1004-1017, 1997.

[6] Bradshaw, J.,Nicholls, M. and Rogers, M., “An Intermanual Advantage for Tactual Matching”, Cortex, vol. 34, no. 5, pp. 763-770, 1998.

[7] Craig, J., “Attending to two fingers: Two hands are better than one”, Perception & Psychophysics, vol. 38, no. 6, pp. 496-511, 1985.

[8] Friedman, A. and Polson, M., “Hemispheres as independent resource system: Limited-capacity processing and cerebral specialization.”, Journal of Experimental Psychology: Human Perception and Performance, vol. 7, no. 5, pp. 1031-1058, 1981.

[9] Friedman, A., Polson, M., Dafoe, C. and Gaskill, S., “Dividing attention within and between hemispheres: Testing a multiple resources approach to limited-capacity information processing.”, Journal of Experimental Psychology: Human Perception and Performance, vol. 8, no. 5, pp. 625-650, 1982.

[10] Friedman, A., Polson, M. and Dafoe, C., “Dividing attention between the hands and the head: Performance trade-offs between rapid finger tapping and verbal memory.”, Journal of Experimental Psychology: Human Perception and Performance, vol. 14, no. 1, pp. 60-68, 1988.

[11] Iida, N., Kuroki, S. and Watanabe, J., “Comparison of Tactile Temporal Numerosity Judgments Between Unimanual and Bimanual Presentations”, Perception, vol. 45, no. 1-2, pp. 99-113, 2015.

[12] Kinsbourne, M. and Cook, J., “Generalized and lateralized effects of concurrent verbalization on a unimanual skill”, Quarterly Journal of Experimental Psychology, vol. 23, no. 3, pp. 341-345, 1971.

[13] Pashler, H. and O’Brien, S., “Dual-task interference and the cerebral hemispheres.”, Journal of Experimental Psychology: Human Perception and Performance, vol. 19, no. 2, pp. 315-330, 1993.

[14] Welford, A., “The ’Psychological Refractory Period’ and the Timing of High-Speed Performance-A Review and A Theory”, British Journal of Psychology. General Section, vol. 43, no. 1, pp. 2-19, 1952.

[15] Highland, R. and Fleishman, E., “An empirical classification of error patterns in receiving Morse Code.”, Journal of Applied Psychology, vol. 42, no. 2, pp. 112-119, 1958.

[16] Schlaffke, L., Ruther, N., Heba, S. et al., “From perceptual to lexico-semantic analysis-cortical plasticity enabling new levels of processing”, Human Brain Mapping, vol. 36, no. 11, pp. 4512-4528, 2015.

[17] Verlaers, K., Wagemans, J. and Overvliet, K., “The effect of perceptual grouping on haptic numerosity perception”, Attention, Perception, & Psychophysics, vol. 77, no. 1, pp. 353-367, 2014.

[18] Erp, J. and Spapé, M., “Time-Shrinking and the Design of Tactons”, EuroHaptics, pp. 289-294, 2008.

[19] Dim, N. K., and Ren, X. Investigation of suitable body parts for wearable vibration feedback in walking navigation. International Journal of Human-Computer Studies, 97, 34-44, 2017.

[20] Heller, M. A., Rogers, G. J., and Perry, C. L., “Tactile pattern recognition with the Optacon: Superior performance with active touch and the left hand”, Neuropsychologia, 28(9), 1003-1006, 1990.

[21] Bloom, J.. “A Standard for Morse Timing Using the Farnsworth technique” ARRL laboratory, 1990.

[22] Allan, M., “A Pattern Recognition Method of Learning Morse Code”, British Journal of Psychology, vol. 49, no. 1, pp. 59-64, 1958

[23] Boldt, R., Gogulski, J., Guzman-Lopéz, J., Carlson, S. and Pertovaara, A., “Two-point tactile discrimination ability is influenced by temporal features of stimulation”, Exp Brain Res, vol. 232, no. 7, pp. 2179-2185, 2014.

[24] Csapó, A., Wersényi, G., Nagy, H. and Stockman, T., “A survey of assistive technologies and applications for blind users on mobile platforms: a review and foundation for research”, Journal on Multimodal User Interfaces, vol. 9, no. 4, pp. 275-286, 2015.