Pilot Study for the Nonvisual Depth Perception Device Efficacy

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Abstract

Sensory substitution and augmentation are the translation of one sense modality into another whether it is novel to the user or not. This can include devices that translate sight to tactile sensations (substitution), or even magnetic field detection to vibrations (augmentation). I report my novel sensory augmentation device, “the nonvisual depth perception device,” that translates backward depth perception into vibrations on the neck. Through two sets of trials, the device was found to significantly improve accuracy on guessing where an object was behind the user. Accuracy and reaction time did not change in general across trials, and performance did not significantly differ when a user was distracted or not.

*Keywords*: sensory substitution, sensory augmentation, tactile, depth perception
Pilot Study for the Nonvisual Death Perception Device Efficacy

Sensory substitution, as paraphrased from Renier and de Volder (2005), is the use of one sense organ to substitute the information gathering of another sensory organ. This substitution then encodes the information from one modality into another. An example could be translating the brightness seen by an optical camera into electrical stimulation of the tongue. Here, the modality of sight is transformed into the modality of taste and touch thus substituting the sense of sight for a person. Such a device is already in existence as the BrainPort developed by Wicab, Inc.

Sensory substitution has been studied since the late 1960s, and, as a field on its own, has given insight into human perception and brain plasticity (Renier & de Volder, 2005). This was done first by Bach-Y-Rita (1969) in his pivotal study entitled “Visual Substitution by Tactile Image Projection.” Sensory substitution was first coined as a phrase in this paper. It covered the first sensory substitution device that allowed blind people to see with a camera system connected to an array of vibrating motors on their back. The study was able to show that blind people could perform as well as sighted people in tasks involving the camera system. In fact, Bach-Y-Rita had shown evidence of brain plasticity. Instead of a static neural network, the brain was able to adapt to new stimuli (Bach-Y-Rita, 1996).

From further research of the device and subsequent sensory substitution systems, it was found that the back had a greater sensitivity than previously thought possible. Bach-Y-Rita reported that it was held as fact that the back could not discern between two points of stimulation within two inches. Through his first study and subsequent ones, Bach-Y-Rita (e.g., 2004) showed that regardless of what happens at an instantaneous moment, the body is able to perceive
more information across time than at one instance. In essence, he argued sensory perception is defined by movement rather than actual information gathered.

This paradigm has been studied extensively and is the point of much debate as O’Regan and Noë report (2001). They hypothesized that sight consciousness is actually the result of action rather than some complex inner representation of everything seen visually. As the study’s publication shows, there were many arguments for and against it with scientists weighing on both sides in an extensive open peer commentary that followed with the published article (O’Regan & Noë, 2001).

Lenay, Gappene, Hanneton, Marque and Genouelle (2003) cover the extent of this perception and sensory substitution as a whole. They reviewed all the tactile based sensory substitution devices that currently exist. They showed that far from being limited to one or two devices that try to do the same thing, the field is burgeoning and has multiple devices for multiple senses. The authors even created a simple light detection device to delve into the “perception as action” debate. Their results showed that as long as the user had control of the device, his or her conscious awareness would adapt with the new information. As soon as control was removed, this perception would disappear (Lenay et. al, 2003).

From the work in sensory substitution, it was inevitable that development in technology would soon lead to more extraordinary devices. Nagel, Carl, Kringe, Martin and Konig (2005) report the development of their device: a belt that vibrates to true north. This is a twist on sensory substitution into the realm of sensory augmentation. Instead of replacing lost senses, this device gives a brand new sense of orientation in a form recognizable to the body – as vibrations. Their study is actually inspiration for this pilot study. Their work showed what general hypotheses to test in sensory augmentation devices. Primarily, it is important to see that a new
device actually works as planned – helping in some way. Then, it should be shown that the using the device becomes integrated with conscious thinking and even subconscious thinking (Nagel et al., 2005).

Another entry into this field of new tools is a device I developed. Called the “nonvisual depth perception device” (NDPD), it is a sensory augmentation device like the one created by Nagel and others. The device notifies users of incoming objects from behind their visual field. It functions as a glorified proximity sensor that, unlike a standard motion detector, quickly notifies the user where the incoming object is coming from. Vibrations on the neck notify the user by the use of small motors attached by Velcro to a user’s neck. The device is further explained in the Method section.

Just as Nagel (2005) and others had to prove that their device actually helped the user, I seek to do the same for the NDPD. The pilot study of my device is the focus of this paper. The goal of this study is to determine the NDPD’s effectiveness in notifying users of oncoming objects behind their visual field. After the effectiveness is shown, the device needs to be tested to see that users adopt it into their conscious experience. Although this is only a pilot study, an attempt will be made to test the utility of the sensory augmentation device.

The NDPD augments a wearer’s perception by giving retro-depth perception. I hypothesize that accuracy of detecting where an object is behind a wearer is higher while using the device than not. This hypothesis essentially concerns whether the device works. A second hypothesis is the reaction time will decrease, and accuracy will increase with continued use of the device and thereby show that the brain adapts and learns to use new information. Finally, the third hypothesis is the accuracy of a wearer detecting objects while distracted is comparable to no-distraction tests. This last test is an attempt to see that information from the NDPD is
integrated with other sensory stimuli rather than something that has to be consciously concentrated on.

**Method**

**Participants**

The study had a total of 14 participants. All participants were undergraduates at Southern Methodist University, participating in the study for course credit in psychology classes. Their ages ranged from 18 to 21 years, with 12 female participants. Seven participants were white, two were Hispanic, and the remaining five students were Asian.

Each participant filled out a survey concerning the device. In half the cases, the experimenter asked the participants to fill out the survey part way through the study. Because this part of the survey was not done systematically at the same time, this portion of the survey was disregarded.

**Design**

The experiment was divided into two sets of trials. The first set was used to test the hypothesis that the device would improve accuracy at identifying which panels are activated. It would also test to determine if participants improve their accuracy and reaction over time through four separate, consecutive trials. There were eight panels that needed to be activated in three separate conditions. The three conditions were: within range of the device, out of range, and the null case (i.e., no activation). In the null case, the computer randomly chose one of the panels to activate, but the test administrator did not activate the panel. In effect, the participant had no way of knowing which panel to choose. The hope was to get a baseline “random” guessing accuracy to compare against the other two conditions. Each panel would be activated
in the three conditions four separate times. The result was an 8 (panels) x 3 (conditions) x 4 (trials) factorial design.

The second set of trials was similar to the first and used to test the hypothesis that a distraction case would not have significantly lower accuracy than a non-distraction case. In this set, there were two conditions: the distraction and non-distraction case. The distraction case would be tested in the second set of trials. The non-distraction case was already tested in the previous set of trials as the within-range condition. Participants were asked to count backwards from arbitrary starting points in the distraction case. The mental math distracted participants while they still had to guess which panel was activated. This second set of trials was intended to show whether participants could use the device while other information was being processed concurrently. This set had an 8 (panels) x 2 (conditions) x 4 (trials) factorial design.

Materials

Device. Worn like a backpack, the nonvisual depth perception device (NDPD) had four parts: a power source that ran on battery power or wall outlet, a Kinect camera that determined how far away objects are, a computer to process the Kinect information, and vibrating motors to signal the wearer. There were eight vibrating motors attached to two strips of Velcro. These motors were pressed up against the back of the user’s neck and held in place by the Velcro straps.

The motors vibrated whenever a certain part of the visual field that Kinect saw was within proximity. Generally, anything four feet or closer to the camera would activate the motors. They turned on according to where the object is. For instance, if a person walked from left to right within four feet behind the user, the user would feel the motors turn on in sequence from left to right.
**Experimental Apparatus.** This structure was built to test the functionality of the NDPD. It had four columns of two wire frame boxes. Each box had a hanging file folder attached to the bottom that opened by a pull string. Once opened, the folder blocked the front of the box thus making it look like a panel to the Kinect camera. There was enough surface area to activate the motors on the NDPD. In effect, by pulling one of its strings, the apparatus could activate only one of the vibrating motors.

**Program.** A Java program was written to conduct the tests. This program logged the key strokes by the wearer to determine if he or she properly identified which panel was activated. The program also tracked the counter balancing between users and gave a script to the test administrator. The test administrator followed the on-screen prompts and pulled the strings to activate panels according to the instructions.

**Questionnaire.** A four item questionnaire was given to each participant to gather participant demographic data. The questionnaire also had four four-point Likert-type scales to fill out pre- and posttest. The questions concerned how comfortable, irritating, distracting, and easy to use the device was. The goal was to test whether the participants’ attitudes changed about the device after wearing it for the study. As mentioned earlier, the results of the questionnaire had to be discarded.

**Procedure**

The procedure consisted of the participant coming to the laboratory, signing the informed consent form, filling the first part of the survey, doing the first set of trials, completing the second set of trials, filling out the remainder of the survey, and then receiving the debriefing. The training for the device consisted of putting the device on the participant and explaining how it worked. To have the greatest effect on the influence of learning on reaction time and accuracy,
the participant was only given minimal instructions during this time. To minimize discomfort, participants were allowed to put on the Velcro straps around their necks with minimal assistance from the experimenter. Next, the device was turned on and participants were told how the device worked and were told how to use the device. A standardized demonstration was also provided. This involved the experimenter passing behind the participants from left to right to demonstrate how the vibrating motors would activate and allow them to locate objects behind themselves.

Participants then took a seat in a chair facing away from the apparatus. The Kinect camera was detached from the device and placed in front of the apparatus to detect activated panels. After giving participants a keyboard with eight keys marked 1 through 8, the experimenter explained how the testing would work. He then silently read the prompt off of the computer program on a laptop and began the first set. During the trials, the participants were informed when they were right or wrong in identifying which panel was activated and what the correct answer was. The participants heard a beep from the laptop to let them know that a panel was activated and it was time to make a guess. After going through the first set of trials, the participants were given a five minute break if they so choose. The second set of trials followed in the same fashion as the first, but every new trial had the participants counting backwards by a new number. First, participants counted back by three from 100, then seven from 150, nine from 175 and finally six from 173. This is a commonly used procedure to provide a competing cognitive activity for the participant (e.g., the backwards counting keeps the mind occupied to prevent concentration on what panels are moving).

Analysis of the Data

Of the 13 participants that went through the study, there were 13 instances of erroneous data. This would include faults on the experimenter’s part or the apparatus or device. The most
common occurrence was the device not registering the bottom right panel. This would cause a long reaction time for participants as they waited for the device to finally register the moved folder. To handle these skewed results, whenever a data point was tainted due to one of these errors, its reaction time was compared to the other seven reaction times in the group of eight. If the skewed reaction time was the maximum, then the value was replaced by the next highest maximum. This avoided issues of large outliers. For instance, there was one case where there was a reaction time of 20 seconds for one motor but only three seconds for the others.

The final data was collected together to have every data point collected from all participants located in one file. Each data point has: the expected button response, the participant button response, whether that is correct or incorrect, the reaction time, the condition (null, far, close, or distraction), what trial it was, the ID number of the participant, and finally if the value was flagged. From this, each condition x trial combo was created, giving 16 total columns of data (four conditions x four trials each). For accuracy, for every participant that completed one of the conditions in one of the trials, the number of correct responses over the total eight was reported. This gave columns of 13 percentages for every one of the 16 columns. For reaction time, all the reaction times corresponding to the particular column were reported for all participants. This led to 104 rows (13 participants x 8 panels) for the 16 columns.

Results

As can be seen in Table 1, the accuracy and reaction time fluctuated across the trials for each condition and across the conditions themselves. There was an increase in accuracy from the NOT conditions (null) and the CLOSE conditions ($M = 0.12$ to $M = 0.48$). The confidence interval at 95% confidence was also calculated for each of the condition/trial combinations.
Using single factor ANOVA testing, I compared the trials within each of the cases. There was no significant difference in accuracy for the null case, far case, close case, and distraction case across all four trials ($ps = 0.53, 0.59, 0.79, 0.47$, respectively). Curiously, there was significant difference in reaction time for the null and far case ($ps < 0.001, 0.001$), but no significant difference for close and the distraction case ($p = 0.41, 0.86$).

The next round of single factor ANOVA testing was used to compare the last trial of the null case, far case, and close case. This was chosen to determine if there was any difference in learning that occurred through four trials that would be negated if just the last trial was chosen for all three conditions. The difference between the groups was significant for accuracy ($p < .001$) and for reaction time ($p < .001$). When looking at the four trials of the close case and the four trials of the distraction case with ANOVA, there was significant difference between the eight groups for accuracy ($p = 0.03$) and no significant difference for reaction time ($p = 0.80$). Finally, the last trial of the close condition was tested against all four distraction conditions to see if there would be any difference. There was no significant difference between the five groups in accuracy ($p = 0.08$). There was also no significant difference between the five groups in terms of reaction time ($p = 0.89$). The results from the ANOVA are summarized in Table 2.

Paired two-sample $t$-tests were also used to compare the difference between groups of two cases per trial at a time. The first comparisons were made between the last trial of the close condition to the last trial of the null and far. This was done to confirm the results that there was a statistical difference between the three groups through ANOVA. The close condition was significantly greater from null and far in terms of accuracy ($ps < .001$). The one-tail $p$-value was used because the hypotheses stated that close would be greater than null or far. The reaction time also was significantly higher with close than null or far ($ps < .001$). This time, no
predictions were made as to which would have a greater reaction time so the two-tail p-value was reported.

The two-sample $t$-tests were also used to test the mean differences in the close trials by looking at the mean difference between the first and second, second and third, third and fourth, and then first to fourth. In terms of accuracy, there was no significant difference between the first and second trial ($p = 0.14$), second and third trial ($p = 0.42$) and third and fourth ($p = 0.44$). There was also no significant increases between the first and third, second and fourth, and first and fourth ($ps = 0.15, 0.37, 0.17$). The reaction time paints a different picture with a significant decrease between the first and third trial ($p = 0.02$), and first and fourth ($p = 0.04$). There were no significant differences between the first and second, second and third, third and fourth, and second and fourth ($ps = 0.32, 0.08, 0.28, 0.13$). The results of the paired two-sample $t$-tests are summarized in Table 3.

**Discussion**

In summary, the use of the device led to a substantial increase in accuracy. Using the device across time did not lead to an increase of accuracy or decrease in reaction time though. And finally, there was some difference in reaction time and accuracy between being distracted and not. While there are some limitations to the design, the major concerns of biased data due to the design of the study did not occur.

**Hypothesis Support**

Looking over the significance of the mean differences, it is clear there was some interaction of the use of the device compared to not at all (null case) or with it out of range (far case). The first hypothesis states that the close condition would do better accuracy compared to the far or null condition. Figure 1 demonstrates how the data supports this hypothesis. The
confidence intervals for the close conditions are far above the confidence intervals of the null and far case. And, as was mentioned in the results, there is a significant difference between three conditions on the last case. This shows that having the device within range of the panels improved accuracy.

The resounding support of the first hypothesis lends credence to the fact that the device does work as planned. It allows a user to accurately judge where an object is approaching from behind. What is interesting to note is that reaction time was heavily influenced by the null case rather than far or close as evidenced by Figure 2. This makes sense as the participants generally did not think about what answer to put for the null case leading to a faster response time. Similar results happened with the far case but not to the same extent.

As mentioned in the results section, the close condition did not have a significant difference across the four trials for both the accuracy and reaction time. Figure 3 shows that the confidence intervals across the four trials stayed within each other’s ranges. This prevented any significant difference to arise between the trials. Hypothesis 2 states that over time, the reaction time will decrease and the accuracy will increase for the close condition. The graph in Figure 3 does not support this hypothesis. While there is a slight dip in reaction time, and a slight uptick in accuracy, the results are not significant to draw support for the hypothesis. It seems that, based on the evidence presented, that accuracy and reaction time stay roughly the same through the use of the device.

It is important to note that more data for the accuracy and reaction time might help differentiate between the four trials. What would be more revealing is a longer exposure to the device. It is quite possible that there is a certain plateau in efficacy that is reached in using a new device. Once mastered, the efficacy could conceivably have a rapid shift upwards to the next
plateau. Thus, given such a short time span, it is hard to be able to draw any real conclusion from this test except that the training phase needs to be longer. Without this longer phase, it is hard to tell if device efficacy improves across time or stays the same.

The final hypothesis stated that the accuracy of the distraction condition would be comparable to the close condition. Figure 4 graphs the accuracy of both the close and distraction condition. The confidence intervals entangle between the close and distraction in all but the third trial. This helps explain why there was significance in the group differences through ANOVA testing of the close and distraction cases. The third trial had the significant difference while the others did not. Thus, I would state that there is weak support for the hypothesis that the results are comparable. Because there is a gap between the confidence intervals in accuracy of the close and distraction case, it is not reasonable to say that the accuracy is comparable between the two.

The weak support for the hypothesis could be changed by providing more trials with the distraction and close cases. This would allow the differences between the two groups to be further emphasized. Another option would be to evaluate how distraction is done. Every participant had to count back by the same numbers. It’s curious that the dip in accuracy comes when participants have to count back by 7 from 150, and 9 from 175. A standardized distraction case is needed that keeps the complexity of the distraction level consistent across all trials. It is quite possible that the difference in accuracy is due to the distraction task given rather than showing any difference from the close condition. Figure 5 also shows the reaction time for the two sets of trials. Here, the results are much more comparable to each other as the reaction time does not seem to change from the close condition to the distraction condition.

Limitations
The first limitation that is evident in the study is the fact that the device began to malfunction. In fact, the device began to stop working consistently after the thirteenth participant. The next two scheduled studies had to be cancelled due to the errors becoming unfixable in the timeframe left for the project. Clearly, this limited my data collection. It also spawned 13 different issues in the data collection that was readily noticed. There could have been subtle errors – delays in the vibrations of the motors randomly – that had already affected my data.

Partly due to the device and time constraints, there was a small sample size for the participants. Unfortunately, only thirteen participants went through the study. Given more time and more proper planning on my part, more participants could have been recruited for the study. Using these new participants, some of the differences in learning for the close condition could have been tweaked out to give a more resolute consensus if the second hypothesis was supported.

Each participant only took thirty minutes to complete the study. While that is a positive experience for the participant, the study had to be severely limited to prevent fatiguing the participant. This presented itself as a limitation, as the amount of trials per condition needed to be reduced. With more studies, it will be easier to test both the second and third hypothesis. There could have been clear evidence for learning if there were more trials for a participant to go through.

Putting aside the above limitations, there were concerns that the study could be tainted due to the design of the apparatus. These were unfounded though as evidenced by the results. One cause of concern for the design of the study was whether there would be a bias towards accuracy increasing as a set of eight panels were tested against the participant. As the participants went through a trial, if they wanted to, they could keep track of the previous panels
that were exposed. By keeping track of the previous panels in the trial for the particular condition, they would have better odds guessing which panel is next to come up. This did not occur as the accuracy for the null case (pure guessing) was around 0.125. This implies that participants did not catch on to keeping track of previous panels that were activated as their guessing was still only as good as chance.

There is an uptick in the far case that is above chance, and that is explained by another concern from the design. Due to the fact that participants did not wear headphones, they could conceivably hear the movements of the folders as panels were activated. This would allow them to narrow the choices by about half by knowing if the sound came from the left or right. And as expected, when looking at the accuracy for the far case, it hovers around 0.25 which would be the probability of blindly guessing only one of four motors.

**Future Work**

The three limitations should be used as guides for improvements in subsequent studies. First, the device should be repaired and reevaluated to make sure it works consistently in future studies. A large subject pool should be planned for next time. Finally, each participant should experience more trials for all of the conditions in order to properly test all of the hypotheses.

On top of those three things, future work could involve looking at the distribution of choices by the users for which panel was activated. Currently, the data has been recorded for which panel was activated and what the user chose. Due to the hypotheses given for this pilot, these data were not looked at. Future analysis of these data or new datasets could look to see if there are correlations between the proximity of the wrong guess and correct answer. It could also look to see if the “learning” of which vibrations correspond to a panel is instantaneous or something developed over a few trials.
There are many research avenues to pursue. Certainly, the NDPD merits further investigation. Its use as a sensory augmentation device could be invaluable with the right application. Before such big leaps are made though, studies like the present one and similar future ones are needed to demonstrate how effective the device is. Future work will need to investigate the limits of the NDPD and just how useful it is for real-world tasks.
References


Table 1

*Statistical Descriptors of Accuracy and Reaction Time across Condition v. Trial*

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<th>Condition x Trial</th>
<th>Accuracy</th>
<th>Reaction Time</th>
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*Note.* Std Dev is standard deviation and S.E. is standard error. The confidence interval was calculated by not listed at 95% confidence. This will be used in the graphing portion.
Table 2

ANOVA Testing Results Summarization

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<th>Accuracy</th>
<th>Reaction Time</th>
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<td>Within group df</td>
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Table 3

*Paired T-Test Result Summarization*

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and third
close

Second close
and fourth  0.3143  12  .3694  1.141  103  0.1283
close

First close
and fourth  1  12  0.1685  1.763  103  0.0404
close

Note. All p-values are one-tailed except for reaction time “Last close and last null” and “Last close and last far” which are two-tailed.
Figure Captions

*Figure 1.* The mean and 95% confidence interval for accuracy graphed across the three conditions from the first half of the experiment for the four trials. Analysis of this graph lends support to the first hypothesis.

*Figure 2.* The mean and 95% confidence interval for reaction time in milliseconds graphed across the three conditions from the first half of the experiment for the four trials.

*Figure 3.* The mean and 95% confidence interval for reaction time and accuracy graphed against the four trials for the close condition. Analysis of this graph does not lend support to the second hypothesis.

*Figure 4.* The mean and 95% confidence interval for accuracy graphed across the close condition and distraction condition. Analysis of this graph lends some support to the third hypothesis.

*Figure 5.* The mean and 95% confidence interval for reaction time graphed across the close condition and distraction condition. Analysis of this graph lends support to the third hypothesis.
Close, Null & Far Accuracy across Trials

Accuracy vs. Trial

- Close
- Null
- Far
Close Condition Across Trials

Reaction Time (ms) vs. Accuracy across different trials. The graph shows the reaction time and accuracy for each trial, indicating a decrease in reaction time and an increase in accuracy as the trials progress.
Close v Distraction with Accuracy

Accuracy

Trial

Close
Distraction
Depth Perception Device Efficacy

Close vs Distraction with Reaction Time

Reaction Time (ms)

Trial

Close
Distraction