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Abstract

Theories of cross-modal plasticity have explored how a certain modality can be repurposed after prolonged loss of input to support remaining modalities. This present study aimed to further understand effects of cross-modal plasticity through an investigation on individuals who have experienced auditory deprivation. Prior research has shown inconsistent results about possible visual advantages which early-deaf individuals may possess. In this study, it was hypothesized that early-deaf individuals would perform better than hearing controls in specific visual tasks, due to functional reorganization of the auditory cortex. It was expected that differential activation would show in visual and auditory cortices of early-deaf individuals over hearing controls, and that higher levels of activation would be correlated with better performance on behavioural tasks. These tasks encompassed a face matching task, a non-biological motion detection task, and a biological motion detection task. Neuroimaging data were acquired using motion and face localizers in a 3T MRI scanner. Participants of this study included 4 hearing controls. Since there were no deaf participants, unfortunately the initial hypotheses could not be tested. Instead, this experiment will be used as a pilot to address concerns in behavioural tasks and localizer data. This present study sets a framework upon which future studies can conduct research to test these hypotheses, such that the understanding of functional specificity in the human brain can be understood.

Keywords: neuroplasticity, cross-modal plasticity, visual advantages, peripheral motion, face processing, auditory cortex, early-deaf, auditory deprivation

Using Visual Stimuli to Investigate Cross-Modal Plasticity in the Deaf

The brain's ability to adapt to change has continued to be one of the most fascinating aspects of research in psychology. Neuroplasticity, a neural process that describes the brain's ability to reorganize in response to experience, can be mediated by life experiences and development as well as environmental influences (Bavelier & Neville, 2002). Cross-modal plasticity describes a type of neuroplasticity where the brain repurposes one modality in response to changes in another. It can be further understood as the adaptation of cortical regions which traditionally represent the absent sensory modality, to respond to the absence and process the remaining intact senses (Karns, Dow, & Neville, 2012).

One way in which researchers study cross-modal plasticity is by investigating populations who have experienced prolonged sensory deprivation, such as people who are blind or deaf. By studying these populations, researchers can examine how other sensory systems are affected by loss of input in a multisensory world. Unfortunately, the research investigating how people with hearing loss respond to visual stimuli has shown inconsistent results. Additionally, it is necessary to understand which brain areas are involved in this response, as that may lead to the discovery of how neuroplasticity can change functional specificity of those regions (Bavelier & Neville, 2002). The focus of the present study is to investigate the effects of hearing loss on the neural representation of visual processing. We will investigate this topic by employing high resolution functional magnetic resonance imaging (fMRI) to map visually-evoked activation within the auditory cortex of the deaf. We will begin by reviewing foundational studies that have presented evidence for cross-modal plasticity and visual advantages in the deaf: specifically peripheral motion processing and face processing. We will then address the limitations of previous studies and what the present study will supply to this body of research.

Cross-modal plasticity research began with investigation into vision loss. Researchers were unaware if sensory deprivation in one domain would impair the development of other senses, termed the perceptual deficit hypothesis, or if it would cause compensatory advantages in other senses, termed the sensory compensation hypothesis (Megreya & Bindemann, 2017; Proksch & Bavelier, 2002). One study that facilitated research into this topic compared peripheral sound localization ability between blind participants and sighted controls (Röder et al., 1999). The researchers hypothesized that the effects of vision loss may enhance sound processing in the periphery (Röder et al., 1999). When individuals orient themselves to sound, vision helps to modulate the spatial awareness they have; congenitally blind individuals do not develop this visual-spatial awareness and thus, their auditory spatial awareness becomes more detailed (Röder et al., 1999). In Röder et al.'s (1999) study, participants were instructed to attend to one central speaker and one peripheral speaker. Alongside each speaker were three deviant speakers (six total). Participants were asked to determine if the sound played from the speaker they were instructed to attend to, or if the sound was deviant. Their results showed that blind participants displayed superior sound localization abilities in peripheral space, as their ability to decipher deviant stimuli was much more accurate than the sighted controls (Röder et al., 1999). This study helped to showcase the phenomenon of cross-modal plasticity, as it was one of the first experiments to show an advantage the blind had in terms of sound localization. These were exciting results that allowed researchers to understand that compensatory effects can occur with loss of a sensory domain, supporting the idea of cross-modal plasticity.

Röder et al.'s (1999) findings aided in providing researchers a basis for their hypotheses, and investigations began to look at how cross-modal plasticity plays a role in different types of sensory deprivation. It cannot be assumed that sensory deprivation in one modality will have the

same plastic effects cross-modally as sensory deprivation occurring in another modality. Thus, researchers began this investigation by testing deaf participants to determine if they have any differences in responses to visual stimuli when compared to hearing controls.

Peripheral Motion Processing

In one of the first cross-modal plasticity studies in deaf humans, Neville and Lawson (1987) investigated focused attention to central and peripheral visual stimuli in congenitally deaf participants using a movement detection task. They determined that when central stimuli were presented, deaf participants and hearing controls performed comparably, but when peripheral stimuli were presented, deaf participants were faster and more accurate in detecting motion (Neville & Lawson, 1987). In their study, deaf participants also showed a much larger increase in event-related brain potentials (ERPs) than hearing controls when stimuli were presented in the periphery, as well as when stimuli were moving (Neville & Lawson, 1987). These results provide evidence of major differences in the systems mediating attention to visual space and perception of motion in the deaf (Neville & Lawson, 1987). They hypothesized that the increased attention effects could be attributed to a lack of competition from auditory input, thus resulting in an increase in the visual response (Neville & Lawson, 1987). They offer an alternate explanation as well: that neurons normally used in auditory processing would be repurposed for use in the visual system (Neville & Lawson, 1987). As one of the initial studies investigating cross-modal plasticity, with little knowledge to base hypotheses on, Neville and Lawson's (1987) study brought light to the potential implications which could result from replication of their findings. To understand if the differences they found resulted from cross-modal plasticity, replication of this study needed to occur using neuroimaging methods. By using neuroimaging methods,

differential activation in specific cortical regions could be shown as a result of functional differences between deaf and hearing participants.

Finney, Fine, and Dobkins (2001) investigated the effects of hearing loss on processing visual stimuli in the auditory cortex. They conducted this study by presenting a moving dot pattern to both early-deaf and hearing participants, and used fMRI to measure visually-evoked activity in the auditory cortex (Finney et al., 2001). Their results showed differential activation in the right auditory cortex of deaf participants, which was not seen in hearing controls (Finney et al., 2001). The areas of visually-evoked activation corresponded with Brodmann's areas 42 and 22, which are secondary and association auditory areas, as well as Brodmann's area 41, which is part of the primary auditory cortex (Finney et al., 2001). Finney et al. (2001) suggested the possibility that these areas of activation may be due to a predisposition of motion processing in the right hemisphere of the brain. In another version of their experiment where participants were asked to ignore the moving dot pattern rather than attend to it, they found a smaller region of effect but still observed activation in the deaf (Finney et al., 2001). From this, researchers were able to conclude that the deaf may have better ability to perceive motion even when not attending to it, attesting to the strength of the cross-modal plasticity effect (Finney et al., 2001). Finney et al. (2001) state how Brodmann's areas 42 and 22 may both be involved in visual language processing for the deaf, as shown in prior studies (Calvert et al., 1997; Petitto et al., 2000). However, readers should interpret these results with caution due to limitations presented by imaging techniques at this time. Additionally, Finney et al. (2001) defined their auditory region of interest (ROI) by playing music sequences to their hearing participants. This could have introduced several limitations because of the hemispheric asymmetry of music processing, as

well as because they only analyzed visually-evoked fMRI responses within that functionally-defined auditory ROI (Finney et al., 2001).

A more recent study investigated the abilities to localize motion and to discern different directions of motion in the deaf (Hauthal, Sandmann, Debener, & Thome, 2013). Researchers used a dot pattern that employed coherently-moving and static dots to test detection accuracy for localization and direction of motion (Hauthal et al., 2013). Results showed that the deaf displayed a left visual field advantage for localization of motion, as well as faster and more accurate detection of motion direction (Hauthal et al., 2013). However, they did not find any differences between the deaf and hearing reaction times during the localization task, which may have been due to a ceiling effect as there was high accuracy at all speeds of movement across both groups (Hauthal et al., 2013). Another limitation of this study includes that some of the participants who were deaf had not become so before the age of acquiring spoken language.

As Hauthal et al.'s (2013) results contrasted Neville and Lawson's (1987) finding of a right visual field advantage, it is imperative to conduct further research to explore these conflicting results. Finney et al.'s (2001) study, which showed a predisposition of motion processing in the right cortex, may support this result from Hauthal et al.'s (2013) study, as the visual pathway acts contralaterally. However, it is difficult to draw concrete conclusions in light of the mixed results presented.

Face Processing

Another hypothesized visual advantage that the deaf possess is face processing. A study conducted by Megreya and Bindemann (2017) investigated the effects of hearing loss on face perception. After reviewing prior literature, they stated that face processing needed to be reevaluated due to several mixed findings where face and object identification advantages have

not been consistently found in the deaf (Megreya & Bindemann, 2017). Megreya and Bindemann (2017) suggested that these inconsistencies are likely due to target eccentricity and selective visual attention. Additionally, the majority of prior literature has focused on the possibility of peripheral motion processing advantages, and more investigation needed to be conducted to explore results of face processing (Megreya & Bindemann, 2017). In their study, Megreya and Bindemann (2017) used a task that relied less on memory and more directly on face encoding, where participants were asked to match a target face to a ten-face line-up. Here, a different image of the target would be either present or absent in the line-up. The researchers included another task using inverted faces as well as one which was purely object matching, to determine if deaf participants held a general visual identification advantage or a face-specific advantage (Megreya & Bindemann, 2017). Results demonstrated a general visual processing advantage in deaf participants, who performed more accurately than hearing controls in both upright and inverted face tasks as well as the object matching task (Megreya & Bindemann, 2017). Megreya and Bindemann (2017) suggested that additional research is needed in this area to understand the advantages that the deaf have and if these advantages can continue to be replicated for non-facial tasks as well.

A neuroimaging study conducted by Benetti et al. (2017) used face processing to investigate if the deaf brain would recruit an area of the auditory cortex traditionally used when hearing individuals listen to spoken language. Specifically, researchers were looking for activation within the temporal voice-selective area (TVA; Benetti et al., 2017). They tested early deaf individuals and hearing controls by an fMRI face localizer task with two categories: faces and houses. After the fMRI tasks, participants were given a delayed face identification task (Benetti et al., 2017). Their results showed responses in the superior temporal sulcus (STS)

which overlaps with the right mid-TVA (Benetti et al., 2017). This supports the idea of cross-modal plasticity occurring during development as a reorganizational response to sensory deprivation.

The Present Study

In 2002, Bavelier and Neville conducted a review of all prior research conducted on cross-modal plasticity. They highlighted the limitations of prior research and called upon future research to be conducted in needed directions (Bavelier & Neville, 2002). One of the directions emphasized was the use of techniques which could provide higher spatial and temporal resolution, to be able to draw more specific conclusions regarding the brain areas involved in cross-modal plasticity (Bavelier & Neville, 2002). As previously shown by prior studies, higher resolution techniques are needed to be able to accurately draw conclusions about which cortical areas are evoking activation.

Another major limitation of all past studies investigating cross-modal plasticity in the deaf population is the poor quantification of sign language proficiency. Sign language may affect visual processing because it is a visual language, and thus it is necessary to measure proficiency of sign language in more detail. To determine sign language proficiency, prior studies have solely used self-report methods to establish the capabilities of their participants. Unfortunately, self-report introduce a subjective measure of how well one understands sign language. Thus, an objective test of sign language is needed to determine if there are any gradient effects for visual advantages that can be exposed when looking at different levels of sign language proficiency. We hypothesize that with more sign-language experience and proficiency, there may be more activation present in the deaf auditory cortex for these specific visual tasks.

Based on the prior literature, there does exist converging evidence for behavioural enhancements in visual processing in the deaf population, as shown by increased activation in the auditory cortex. However, it has been emphasized that these enhancements are highly specific (Bavelier, Dye, & Hauser, 2006). A more recent comprehensive review attempted to determine how visual cross-modal plasticity occurs in the deaf (Alencar, Butler, & Lomber, 2019). By reviewing findings from behavioural, physiological, and anatomical studies, Alencar et al. (2019) were able to illustrate that cross-modal reorganization was responsible for the visual advantages possessed by the deaf population. One common feature to note throughout all previously reviewed studies is that the plastic changes observed are specific to certain visual abilities, and are not a general visual advantage that the deaf possess. Although there has been prior research investigating peripheral motion processing, to our knowledge, no prior research has been conducted on peripheral face processing, and only a few studies conducted in regards to central face processing. We hope through this present study we can introduce this idea of peripheral face processing as another advantage seen in the deaf population.

It is important to understand the effects of sensory deprivation on brain development, as a large portion of the population does experience hearing loss (Feder, Michaud, Ramage-Morin, McNamee, & Beauregard, 2015). Deafness can negatively impact cognitive and social development as compared to individuals without hearing loss (Schirmer, 2001). It is important to understand these effects of sensory deprivation to pursue possible behavioural rehabilitation techniques that are well-suited towards the deaf, such as the introduction of cochlear implants (Benetti et al., 2017). Additionally, some researchers have noted that deaf individuals may have a more difficult time focusing on central tasks within distracting environments, like an academic or

work setting (Bavelier et al., 2006). Thus, it is important to be able to solidify knowledge on visual advantages the deaf have, to adequately aid them with their cognitive development.

The brain's ability to reorganize as a response to long-term sensory deprivation in one modality has proven to be robust, and this present study will go forward and extend findings to determine specific brain areas involved as well as replicate findings of advantages. We hypothesize that we will find differential activation in the visual and auditory cortices of deaf participants over those of hearing controls, when faced with two types of visual tasks: peripheral motion processing and face processing. Further, we attempt to determine the role of specific regions of the auditory cortex involved in this process of enhanced performance.

Method

Participants

This study recruited adult participants between the ages of 18 and 80 years old, who self-reported normal hearing or were diagnosed with some degree of hearing loss. In this study, there were four individuals of normal hearing. Hearing and deaf participants would have been matched across groups for age and IQ. Ages of the participants ranged from 21 to 35 years ($M = 27$; $SD = 5.79$). Of the four participants, one was male, and three were female. Eligibility criteria outlined that the participants had normal or corrected-to-normal eyesight and no known neurological disorders. Hearing participants had no pure tone threshold exceeding 20db Normal Hearing Level. For deaf participants to be eligible, they must have had pure tone thresholds exceeding 90dB. Hearing aid use was not an exclusion criterion, but cochlear implants were due to contraindications with the MRI. Participants were recruited using poster advertisement at Western University as well as in the surrounding London community (see Appendix A). Additional recruitment efforts were made through existing databases like BrainsCAN and the

H.A. Leeper Speech & Hearing Clinic at Western University, as well as through a student research participant pool (SONA) at Western University. Participants received monetary compensation for their participation in this study, or credit for course participation if recruited through SONA. This study was approved by the Western University Health Sciences Research Ethics Board (see Appendix B).

Materials

Demographic questionnaire. The demographic questionnaire contained 22 items encompassing personal questions as well as questions regarding visual and hearing abilities (e.g. "*Are either of your parents or other family members deaf? (YES/NO) If yes, please state who and the cause (if known)*"; see Appendix C).

IQ test. The Test of Nonverbal Intelligence (TONI-4; Brown, Sherbenou, & Johnsen, 2010) was used to assess non-verbal IQ of the participants (see Appendix D).

Sign language test. Deaf participants were given the American Sign Language Comprehension Test (ASL-CT; Hauser et al., 2015) to formally assess their sign language proficiency level (see Appendix E). This test allowed for an objective level of sign language proficiency to be assessed.

Face matching task. The face matching task was developed from the Glasgow Unfamiliar Face Database (Burton, White, & McNeill, 2010) and adapted to suit this study (see Appendix F). A subset of 160 faces were chosen and greyscaled to avoid colour matching. Faces in the database were already cropped to have no background. For this study, they were presented on a white background. Forty sets of four different faces were created based on high similarity to each other. Similarity ratings were provided in the face database based off a sample of 30 raters (Burton et al., 2010). This allowed for 160 distinct trials, where each face in each set was used as

the target face once and as the distractor three times. The target match in the set was always a different picture of the target person. The trials were split into four conditions with the target face presented centrally or peripherally, and upright or inverted (central/upright, central/inverted, peripheral/upright, peripheral/inverted). The peripheral conditions were developed with the midpoint of the target face at 10 degrees either left or right from the central fixation cross. Left and right presentations in peripheral conditions were randomized. The set of four faces was always presented upright, in a 2 by 2 grid centered around the fixation cross.

Apparent motion task. The apparent motion task presented a white square in position A, and then in quick succession, another white square in position B. This created the illusion of motion, where the second square was presented in one of eight directions (see Appendix G). The size of the square was 0.5 by 0.5 degrees visual angle, and the distance of apparent motion appeared as large as 0.5 degrees to as little as 0 degrees. It was presented against a grey background. The square was presented in two conditions: centrally and peripherally. The peripheral condition was developed with the midpoint of the square at 10 degrees either left or right from the central fixation cross. Peripheral side presentation (left, right) was randomized. A staircase method was used to determine participants' thresholds, with nine reversals. The distance of the apparent motion began at 0.5 degrees. As participants progressed through the reversals, the apparent distance was reduced by decreasing amounts for each reversal (step sizes: 0.125, 0.125, 0.125, 0.06, 0.03, 0.01, 0.007, 0.003, 0.001). This was the same for both the central and peripheral conditions of this task. For one correct response, the staircase would step up, and for three incorrect responses, the staircase would step down. Staircasing thresholds converged at the 77.85%-correct points (García-Pérez, 1998).

Biological motion task. The biological motion task presented a point-light walker consisting of 13 dots, which was overlaid with an array of randomly-moving dots (stimuli from Vanrie & Verfaillie, 2004; see Appendix H). This clip consisted of white dots against a black background. The array of dots overtop the point-light walker began at one dot and could increase to a maximum of 2000 dots. This task was presented both centrally and peripherally, with the point-light walker presented upright as well as inverted, creating four conditions (central/upright, central/inverted, peripheral/upright, peripheral/inverted). Again, a nine-reversal staircasing method was used to determine participants' thresholds. Staircasing thresholds converged at the 77.85%-correct points (García-Pérez, 1998). In the central conditions, dots increased by lessening amounts as the participant progressed through the reversals (step sizes: 32, 32, 32, 16, 8, 4, 2, 1). In the peripheral conditions, the number of dots increased by smaller amounts than in the staircase of the central conditions, due to the increased difficulty of the task in the periphery (step sizes: 16, 16, 16, 16, 8, 4, 2, 1). For every incorrect answer, the staircase would step down, and for three correct answers, the staircase would step up. Stimuli presentations in the peripheral conditions were shown 10 degrees left and right of the fixation cross. Left versus right peripheral presentation was randomized.

Motion localizer. The fMRI motion localizer was developed to include three varieties of motion stimuli: scrambled dots as non-biological movement, a point-light walker as biological movement, and no motion (see Appendix I). Stimuli were presented centrally and in the periphery. Left versus right peripheral presentation was randomized.

Face localizer. The fMRI face localizer was developed to include two types of stimuli: intact upright faces, and scrambled faces (see Appendix J). Faces presented were not part of the 160 faces which made up the face matching task, but were taken from the remaining faces in the

face database (Burton et al., 2010). Again, faces were greyscaled for consistency with the face matching task. Stimuli were presented centrally as well as in the periphery. Peripheral presentations (left, right) were randomized.

Procedure

This study occurred in two sessions. Prior to the experiment, participants were given the letter of information (see Appendix K). In the first session, participants were given the opportunity to review the letter of information, and then gave their informed consent to participate in the study (see Appendix L). At this point, participants filled out a paper survey where they answered questions about hearing and visual ability (see Appendix C). Audiometric thresholds were tested using a series of pure tones over a frequency range of 0.25 to 8 kHz. Visual acuity was tested using the tumbling-E chart, a non-verbal equivalent of the traditional Snellen test. Participants were instructed to complete the TONI-4 to allow for participant matching (Brown et al., 2010; see Appendix D). Then, deaf participants completed the ASL-CT as part of a larger study (Hauser et al., 2015; see Appendix E), as part of a larger study. All participants completed the three behavioural tasks to determine motion detection threshold levels and face matching accuracy in a sound-attenuated chamber. They were seated comfortably at a computer, with a chin rest adjusted to fit the height of each participant, thus keeping their head in the same position throughout the different conditions of the three tasks. Responses were made using a keypad with 8-directional arrow keys. Participants were offered breaks in between tasks. Before each task began, instructions were presented and a practice round was completed with feedback to ensure participants understood the task. Participants were asked to answer as quickly and as accurately as possible. All conditions were presented in a randomized order.

For the face matching task, participants were instructed to match the target face to the set of four faces. The target face appeared for 1 second, and then a visual mask appeared for 0.5 seconds (see Appendix F). Next, all four faces of the set were shown and participants were given 5 seconds to answer before the next trial was presented. Location of the target face in the answer set was randomized. Arrows were shown beside each face in the answer period corresponding to the arrows on the response keypad.

In the apparent motion task, participants were asked to determine which of eight directions the square moved. The fixation cross appeared for 1 second, the first square was presented for 0.33 seconds, and then the second square was presented for 0.33 seconds (see Appendix G). The screen went blank until an answer was given using the response keypad. Participants completed each condition in this task four times such that a more accurate threshold could be determined, by averaging the last five reversals in the staircase over the four trial runs.

In the biological motion task, participants were asked which direction the point-light walker was walking. The fixation cross appeared for 1 second, and then the point-light walker with the array of randomly-moving dots appeared for 2 seconds (see Appendix H). The screen went blank until an answer was given using the left or right arrow keys on the response keypad. Participants completed each condition in this task four times such that a more accurate threshold could be determined, by averaging the last five reversals in the staircase over the four trial runs.

The first session did not last longer than two hours. Upon completion of the behavioural tasks, the second experimental session was scheduled. Participants were compensated at a rate of $5 per 30 minutes. Parking costs were reimbursed.

Only one of the four participants who partook in the first session also completed the second session. The participant was met by a researcher and escorted to the Centre for Functional

Metabolic Mapping at Robarts Research Centre at Western University. All imaging data were acquired on the Siemens MAGNETOM Prisma Fit whole-body 3T MRI Scanner. Upon arrival to the testing area, participants completed a standardized MR safety sheet as per the technician guidelines. Then, they viewed the two localizers in the MRI, where functional volumes were collected. The fixation cross would appear for 6 seconds, and then the stimuli block for 6 seconds. Each localizer lasted approximately six minutes long, and participants were in contact with the experimenter to ensure ongoing comfort. Following the behavioural tasks, resting-state functional volumes and diffusion-weighted images were taken as part of a larger study. Upon completion of the second session, the participant was debriefed and then dismissed (see Appendix M). This session did not last longer than one hour. Participants were compensated at a rate of $15 per 30 minutes for this session. Parking costs were reimbursed.

Results

Behavioural Tasks

For the face matching task, hearing controls performed best in the central and upright condition with a 72% accuracy rate (see Figure 3). This meant they correctly matched 72% of the target faces to its corresponding face in the four-face answer set. Their performance declined in the central and inverted condition with a 60% accuracy rate. Performance accuracy was lowest in the peripheral and upright as well as the peripheral and inverted conditions, where both conditions had a 54% accuracy rate.

For the non-biological motion task, the hearing controls performed best in the central condition, with average thresholds converging at 0.03 degrees of motion (see Figure 2). This meant that they were able to discern the direction of motion of the square with as little as 0.03 degrees of motion. In the peripheral conditions, average thresholds converged at 0.3 degrees for

hearing controls. This meant they had higher motion detection thresholds in the periphery, such that they were only able to detect the direction of motion correctly if the square moved a step of 0.3 degrees or larger.

For the biological motion task, the four hearing controls performed best in the central and upright condition (see Figure 1). If the point-light walker was considered the signal, and the extraneous dots as noise, lower thresholds meant that participants were better able to detect the signal with the addition of more noise. Thresholds converged at approximately 433 dots in this central and upright condition. This meant that an average of 433 dots could be overlaid onto the point-light walker, where the hearing controls were still able to answer the direction of motion correctly. Thresholds converged at fewer dots for the central and inverted condition (281), and even less for both peripheral conditions (peripheral and upright: 53; peripheral and inverted: 24).

Imaging Session (Localizers)

For the imaging experiment within this study, fMRI data were preprocessed using fMRIprep. A first-level analysis was conducted using FSL, corrected for family-wise error (FWE; $p = .05$). From both the motion and face localizers, five sets of functional contrasts were created: (1) central faces (intact and scrambled) > rest; (2) peripheral faces (intact and scrambled) > rest; (3) all motion (biological and non-biological) > rest; (4) biological motion > motion; and (5) intact faces > scrambled faces. All brain areas listed were defined using the Harvard-Oxford cortical and subcortical structural atlases in FSL.

The central faces (intact and scrambled) > rest contrasts included three significant clusters ($p < .05$; see Figure 4). The first significant cluster corresponded to MNI coordinates x = 47.7, y = -85.6, z = -12.3. This cluster overlapped 7% with the right LOC-inferior. The second significant cluster corresponded to MNI coordinates x = -43.5, y = -79.5, z = -7.86. This cluster

had a 77% overlap with the left LOC-inferior. The third significant cluster corresponded to MNI coordinates x = -17.9, y = -101, z = 8.87, and overlapped 68% with the left occipital pole.

The peripheral faces (intact and scrambled) > rest contrasts included two significant clusters ($p < .05$; see Figure 5). The first significant cluster corresponded to MNI coordinates x = -44.3, y = -78.6, z = -8.01. This cluster had a 75% overlap with the left LOC-inferior. The second significant cluster corresponded to MNI coordinates x = 70, y = -35.3, z = 10.5. This cluster had a 20% overlap with the right STG, an 11% overlap with the right SMG, and a 6% overlap with the right MTG.

The all motion (biological and non-biological) > rest contrasts included five significant clusters ($p < .05$; see Figure 6). The first significant cluster corresponded to MNI coordinates x = -44.4, y = -73.4, z = 12.1. This cluster overlapped 55% with the left LOC-inferior and 21% with the left LOC-superior. The second significant cluster corresponded to MNI coordinates x = 41.1, y = -65, z = 1.97. This cluster overlapped 23% with the right LOC-inferior and 7% with the right MTG. The third significant cluster corresponded to MNI coordinates x = -43.4, y = -49.5, z = 9.16. This cluster had an 11% overlap with the left LOC-superior, a 6% overlap with the left precuneus cortex, and a 4% overlap with the left angular gyrus. The fourth significant cluster corresponded to MNI coordinates x = -25.5, y = -69.8, z = 21.7, overlapping 53% with the right LOC-superior and 3% with the right precuneus cortex. The fifth significant cluster corresponded to MNI coordinates x = 70.2, y = -35, z = 10.4. This cluster had a 14% overlap with the left MTG and an 8% overlap with the left SMG.

The biological motion > motion contrasts involved two significant clusters ($p < .05$; see Figure 7). The first cluster corresponded to MNI coordinates x = -2.06, y = 56.6, z = -12.4. This cluster ($p < .05$) had a 68% overlap with the left frontal pole and a 22% overlap with the left

frontal medial cortex. The second cluster corresponded to MNI coordinates x = -33.6, y = -93.3, z = -8.59. This cluster had a 51% overlap with the left occipital pole and a 26% overlap with the left LOC-inferior.

The intact > scrambled faces contrasts corresponded to three significant clusters ($p < .05$; see Figure 8). The first significant cluster corresponded to MNI coordinates x = -45.2, y = -75.5, z = -15.2. This cluster had a 62% overlap with the left LOC-inferior and a 17% overlap with the left occipital fusiform gyrus. The second significant cluster corresponded to MNI coordinates x = 40.5, y = -47.4, z = -29.1, overlapping 2% with the right temporal occipital fusiform cortex. The third significant cluster corresponded to MNI coordinates x = 44.9, y = -88.3, z = -8.43. This cluster had a 22% overlap with the right LOC-inferior and an 8% overlap with the occipital pole.

Discussion

The behavioural tasks conducted outside the scanner revealed expected performance from hearing controls, such that they perform best in central conditions and upright conditions, and worse in peripheral conditions and inverted conditions, across all three behavioural tasks. Predicted data for deaf participants were generated based on results from prior studies. However, since past research has shown mixed results, and these specific tasks have not been conducted, predicted data can only be confirmed upon collection of deaf participant data as an extension of this study.

In the face matching task, it is expected that deaf participants may perform slightly worse than hearing controls in central conditions (see Figure 1). This is likely due to a more diffuse spread of attentional resources to peripheral areas of vision (Bavelier et al., 2006). In the periphery, it is expected that deaf individuals will perform better than hearing controls, since faces may be more salient to a deaf person than a hearing person for reasons related to sign

language use. Additionally, it is expected that deaf participants should be able to discern upright faces versus inverted faces in the periphery, which will be shown by a significantly better performance in the peripheral and upright condition versus the peripheral and inverted condition. Since hearing controls performed similarly in both peripheral conditions (both 54% accuracy), it can be assumed that hearing individuals are unable to discern a face in their peripheral vision from an object which is not a face. However, it is expected that deaf individuals will be able to make this distinction in comparison to hearing controls because of the higher saliency they have towards faces as well as their diffuse spread of attentional resources to the periphery.

In terms of both the biological and non-biological motion detection tasks, it is expected that deaf participants will perform slightly worse than hearing controls in central conditions due to a more diffuse spread of attentional resources (Bavelier et al., 2006; see Figures 2, 3). However, it is expected that deaf individuals will perform better than hearing controls in peripheral conditions, as deaf individuals have shown enhanced peripheral motion detection in prior studies (e.g. Stevens & Neville, 2006). Additionally, these results are expected because of the use of sign language in deaf populations, where peripheral motion may play a role. Peripheral motion detection plays an important role in the lives of those who have lost their hearing; for example, when one cannot hear a car coming up behind them, being able to detect the car in their peripheral vision will help them be more aware of their surroundings.

In terms of the results from the imaging session, central faces (intact and scrambled) > rest and peripheral faces (intact and scrambled) > rest contrasts were created to ensure functional correlates were different within the central versus peripheral tasks. Here, the location of function differs such that the central stimuli has more medial activation, whereas the peripheral stimuli has more lateral activation (see Figures 4, 5). Therefore, it can be assumed that the peripheral

presentations of stimuli reliably test the periphery and are different from the processing of central stimuli.

The activation shown by all motion (biological and non-biological) > rest contrasts overlap with the medial temporal area, or V5, which is associated with motion processing (Born & Bradley, 2005). This activation in V5 supports the motion tasks as reliable tests of motion processing. In biological motion > motion images, it was difficult to discern areas of function which would pertain to biological motion. However, since results only contain one participant's data and the activation can be perceived as mostly noise, it is expected that upon collection of other hearing participant data and deaf participant data, functional activity will be more apparent in areas which pertain to biological motion, like the superior temporal sulcus (STS; Grossman et al., 2000).

The results from the intact faces > scrambled faces contrasts show reliable activation in the occipital fusiform gyrus (fusiform face area), which is known to be involved in face perception (Haxby, Hoffman, & Gobbini, 2000). Activation is also seen in the LOC-inferior, which is additionally known to be responsive to faces (Haxby et al., 2000). Thus, we know that the presented faces reliably elicit activity in areas of the brain associated with face processing.

Alongside the results from the two localizers presented within the scanner, it is expected that deaf participants will also show differential activation over hearing controls when shown peripheral and central faces, peripheral motion, biological motion, as well as peripheral stimuli in general. It is expected that in the deaf participants, this differential activation may come from areas within the auditory cortex region, which is known to be recruited cross-modally to process visual stimuli in the deaf (e.g. Finney et al., 2001).

Although the results of this study are quite preliminary, it is expected that upon collection of data from deaf participants, the predicted hypotheses will be reflected in the data. A correlational analysis will be conducted between the behavioural task results and the localizer results to determine how behavioural performance is related to patterns of brain activation. Unfortunately, since data was collected for only one hearing participant in the imaging session of this experiment, correlations cannot be made between behavioural data and imaging data at this time.

Limitations and Future Directions

One of the limitations of this present study included the small number of participants. As there were only four hearing participants and no deaf participants, the initial hypotheses could not be tested. Rather, this present study will be used as a pilot to address any foreseeable concerns in the behavioural task and localizer data to ensure reliability.

Pertaining to the future of this experiment, the staircases in the biological motion task and the non-biological motion task were modified based on recommendations from a paper about precision of staircases (García-Pérez, 1998). Instead of decreasing step sizes on each reversal, steps were changed to fixed-step sizes on the alternating up and down reversals. Additionally, the number of reversals to end each condition was changed to 15 (from nine), and the number of trials per condition was changed to three (from four). In central conditions of the biological motion task, step sizes were adjusted to: 30, 40, 30, 40, 30, 40, 30, 40, 30, 40, 30, 40, 30, 40, 30 dots. In peripheral conditions, the staircase step sizes were adjusted but still continue to change in smaller amounts than in the central condition, to reflect the increased difficulty of the task in the periphery (step sizes: 15, 20, 15, 20, 15, 20, 15, 20, 15, 20, 15, 20, 15, 20, 15 dots). The non-biological staircase step sizes were adjusted to: 0.015, 0.02, 0.015, 0.02, 0.015, 0.02, 0.015, 0.02,

0.015, 0.02, 0.015, 0.02, 0.015, 0.02, 0.015 degrees. Thresholds continue to converge at the 77.85%-correct points (García-Pérez, 1998).

Another limitation of this study is that an eye-tracking device was not used to determine if participants were properly fixated on the cross during peripheral conditions of behavioural tasks. This can introduce certain confounds to the data, such as if a participant chose to look directly at peripheral presentations of stimuli instead of staying fixated on the cross. Since this is a foreseeable problem considering the saliency of faces as well as the length of certain stimuli presentations (faces were presented for 1 second; point light walkers were presented for 2 seconds), the behavioural tasks were further modified to address this. In the face matching task, presentation time of the target face was reduced to 200ms, which is the length of time the eye saccades from center, meaning the face would have disappeared before a participant is able to direct their gaze to the periphery. The presentation time was modified for both central and peripheral conditions to keep presentation lengths consistent. Since the point-light walker presentation in the biological motion task could not be shortened, as time is needed to display the action of walking, a task was added to the fixation cross to address this issue. This "catch task" involved the red-coloured fixation cross to randomly flash to a white colour approximately 10% of the time. During the instruction period in the beginning of the task, participants will be shown an example of this occurring and will be instructed to keep count of how many times the fixation cross turns white. This fixation cross task was included in all localizer tasks as well, where participants will press a button on a remote during fMRI acquisition when they see the fixation cross turn white (cross turns black in the face matching task as the task is presented on a white background). The goal of this modification was to ensure participants would continue to look at the center of the screen such that the peripheral conditions would reliably test the periphery.

Although the non-biological motion detection task and the face matching task had their stimuli presentation times adapted such that there was no need for a catch task on the fixation cross, during the fMRI localizer tasks, all stimuli were presented for 6 seconds in length. Thus, all localizer tasks needed to include the fixation cross task. In the future, perhaps it would be more ideal if the participants could press a button immediately to account for the colour change of the fixation cross in the biological motion task, like during the imaging session, to avoid any possible confounds with working memory loads. Ideally, the introduction of an eye-tracking device into this experiment, or similar experiments, would be most beneficial to determining that all participant data is accurate and reflective of what the behavioural tasks are supposed to be measuring.

Another direction which must be pursued in the future is the use of a higher resolution imaging technique. Without the introduction of higher resolution techniques, it may be difficult to identify specific cortical regions involved in the neuroplastic changes we may see in the deaf population. Thus, the use of a higher resolution MRI technique in the future would be beneficial if research questions regarding specific cortical areas want to be addressed as a result of differential activation found in deaf participants, over that of hearing controls. This present study did not employ such measures, as the collection of data would cover a long period of time and the 7T MRI scanner, although available, faced continual updates. Although the use of a 7T MRI would make acquired images more detailed, it would not demonstrate consistency across participant data. Furthermore, analysis techniques and packages for 3T data are well developed and widely used, which is not the case for 7T data. Thus, once a scanner of such resolution becomes available for reliable use over time, it should be introduced to studies investigating

similar research questions such that specific cortical areas can be correlated to behavioural data and implicated in these neural processes.

Lastly, one more direction which needs to be addressed is the implications of sign language use and its effects on cross-modal plasticity. Although it is difficult to separate sign language use and hearing loss, the reason for introducing a standardized sign language proficiency test in this present study was to determine if there was a gradient present in deaf individuals, such that higher proficiency would equate to higher functional activation and a greater degree of cross-modal activation. Sign language proficiency has not been implicated in neuroplasticity in the early-deaf, and thus, it is a needed direction that future research should pursue.

Implications and Conclusions

Understanding the functional differences between early-deaf and hearing individuals will help researchers better understand effects of sensory and language experience on functional specificity in the brain. Although results could not provide support for the hypotheses of this present study, it lays a framework upon which future research can be conducted to test these hypotheses. Future research may have implications for changing the stigma surrounding deaf education. For example, understanding the view that deaf individuals are not easily distracted, but rather have a wider spread of attentional resources to the periphery, can help educators understand differences between the hearing and deaf (Bavelier et al., 2006). By studying the possible visual advantages and their neural correlates in the early-deaf, this research can progress the knowledge of functional specificity of the human brain and the understanding of the effects cross-modal plasticity.

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Appendix A

Recruitment Poster

Appendix B

Ethics Approval Form

Western Research

Date: 5 July 2019

To: Dr. Blake Butler

Project ID: 110489

Study Title: Imaging Neural Function and Connectivity in the Deaf

Application Type: HSREB Amendment Form

Review Type: Delegated

Full Board Reporting Date: 16July2019

Date Approval Issued: 05/Jul/2019 10:59

REB Approval Expiry Date: 24/Jul/2020

Dear Dr. Blake Butler,

The Western University Health Sciences Research Ethics Board (HSREB) has reviewed and approved the WREM application form for the amendment, as of the date noted above.

Documents Approved:

Document Name Document Type Document Date Document Version
Info_letter_consent_June20_2019_Clean OurBrainsCAN Tool Questionnaire_20June2019_Clean ResearchProtocol_04Jul2019 Consent Form Recruitment Materials Paper Survey Protocol 20/Jun/2019 2.0 20/Jun/2019 1.0 20/Jun/2019 2.0 04/Jul/2019 2.0

Documents Acknowledged:

Document Name Document Type Document Date Document Version
ResearchProtocol_04Jul2019_Tracked Summary of Changes 04/Jul/2019 1.0

REB members involved in the research project do not participate in the review, discussion or decision.

The Western University HSREB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario

Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Nicola Geoghegan-Morphet, Ethics Officer on behalf of Dr. Joseph Gilbert, HSREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Appendix C

Participant Survey

Western
The Brain and Mind Institute

Project title: Imaging Neural Function and Connectivity in the Deaf

Principal Investigator: Dr. Blake Butler

Personal Information:

1. Study ID #: _____
2. Birth month/year: _____
3. Sex/Gender: _____
4. Current occupation: _____
5. Highest level of education completed:
   a. Elementary School
   b. High School
   c. College Diploma/Undergraduate University Degree
   d. Graduate/Professional Degree (e.g. MA, PhD, MD, LLB)
6. Are you left or right handed? **LEFT RIGHT**
7. Have you ever experienced feelings of claustrophobia (a fear of small or confined spaces)?
   YES NO
8. Have you ever been diagnosed with any neurological or psychological abnormalities (e.g. Schizophrenia, epilepsy, dementia, etc.)? **YES NO**

Hearing Ability:

9. Have you ever been diagnosed with a hearing loss? **YES NO**
   a. If so, when was the diagnosis made? _____
   b. Was the cause of the hearing loss identified? _____
10. Are either of your parents or other family members deaf? **YES NO**
    a. If yes, please state who and the cause (if known) _____
11. Have you ever been prescribed hearing aids? **YES NO**
    a. If yes, when did you receive them? _____
    b. How often did/do you wear them? _____

12. Are you currently experiencing, or have you ever experienced tinnitus (chronic ringing in the ears)? **YES** **NO**

Language/Reading Ability:

13. Do you use a signed language (e.g. ASL, BSL, LSQ)? **YES** **NO**
    a. If so, at what age did you learn it? _____
    b. How many hours per week do you use it? _____
    c. Where did you learn it primarily (school, home, community)? _____
14. Do you use a spoken language (e.g. English, French)? **YES** **NO**
    a. If so, at what age did you learn it? _____
    b. How many hours per week do you use it? _____
    c. Where did you learn it primarily (school, home, community)? _____
15. Do you employ speechreading? **YES** **NO**
    a. If so, at what age did you learn it? _____
    b. What language(s) do you speech read? _____
    c. How many hours per week do you use it? _____
    d. Where did you learn it primarily (school, home, community)? _____

16. Please rate your linguistic ability in all of your known languages (spoken, signed, and speechreading) according to the following scale:

Language	**1 Beginner**	**2**	**3 Intermediate**	**4**	**5 Advanced**	**6**	**7 Native**

17. Please list what percentage of time you are currently and on average exposed to each language (should add up to 100).

Language	**% of exposure**
	= 100%

18. Please list what percentage of time you are currently and on average use each language (should add up to 100).

Language	**% of use**
	= 100%

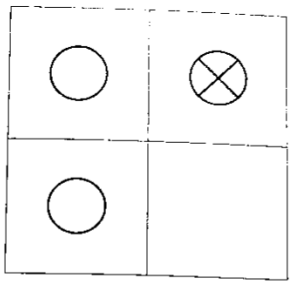
19. Do you have any other difficulties communicating (e.g. speech, spelling, reading)? **YES** **NO**
    a. If so, please describe the difficulty. _____
    _____
    _____
    _____

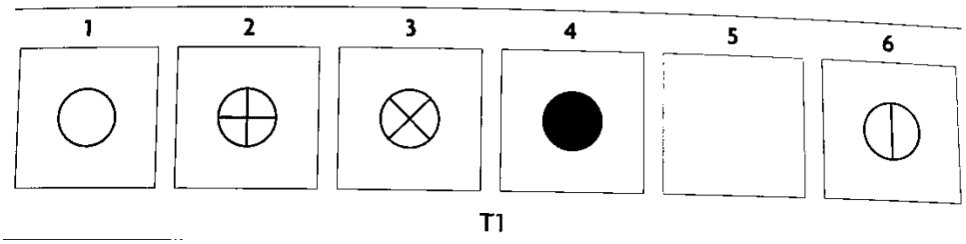
Visual Ability:

20. Do you now, or have you ever worn glasses or contact lenses? **YES** **NO**
    a. If so, what is your prescription? _____
21. Do you play video games?
    a. If so, what kind and how many hours per week on average? What size is your screen and approximately how far from it do you typically sit? _____
    _____
    _____
22. Do you play sports? **YES** **NO**
    a. If so, which sport and approximately how many hours per week do you play?
    _____

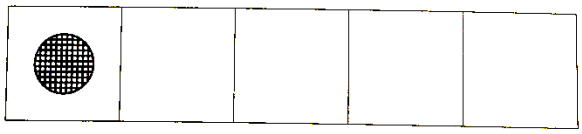
Appendix D

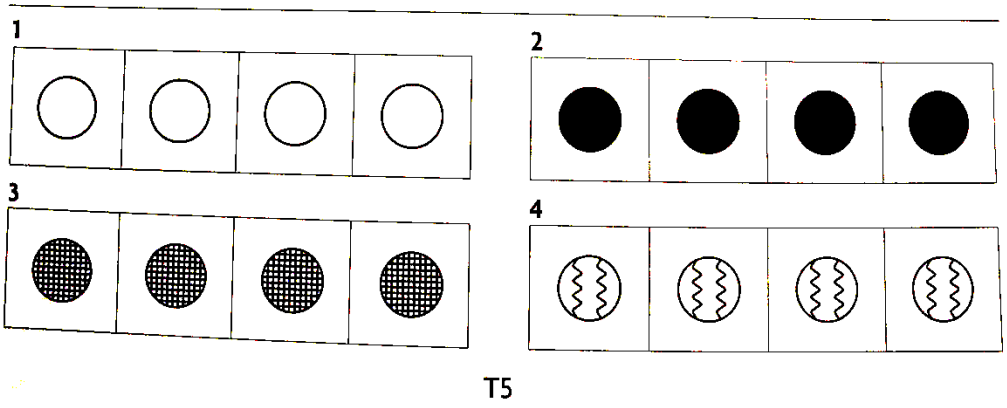
Test of Nonverbal Intelligence (TONI-4; Brown et al., 2010)





Example T1.

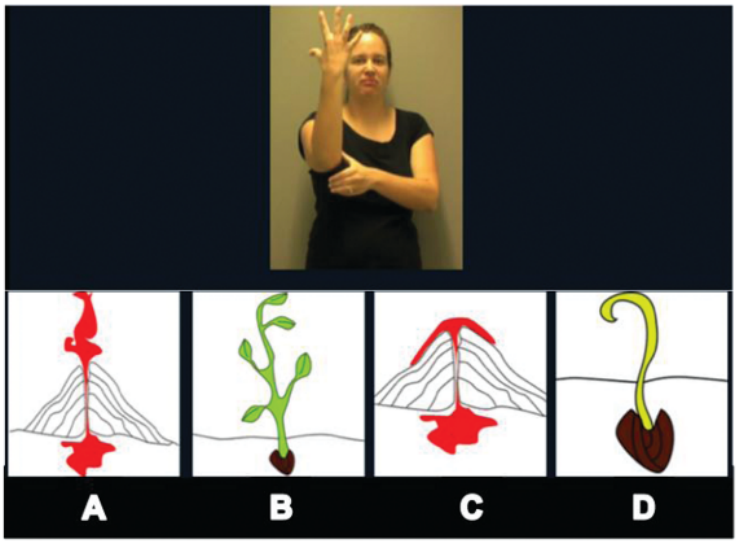




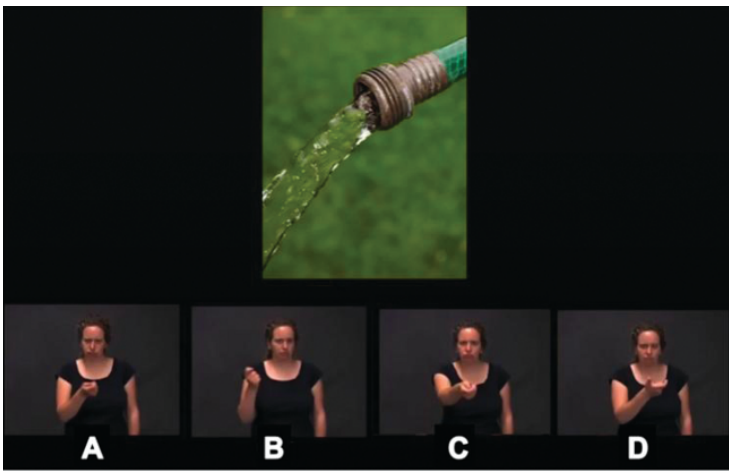
Example T5.

Appendix E

American Sign Language Comprehension Test (ASL-CT; Hauser et al., 2015)



Example 1.

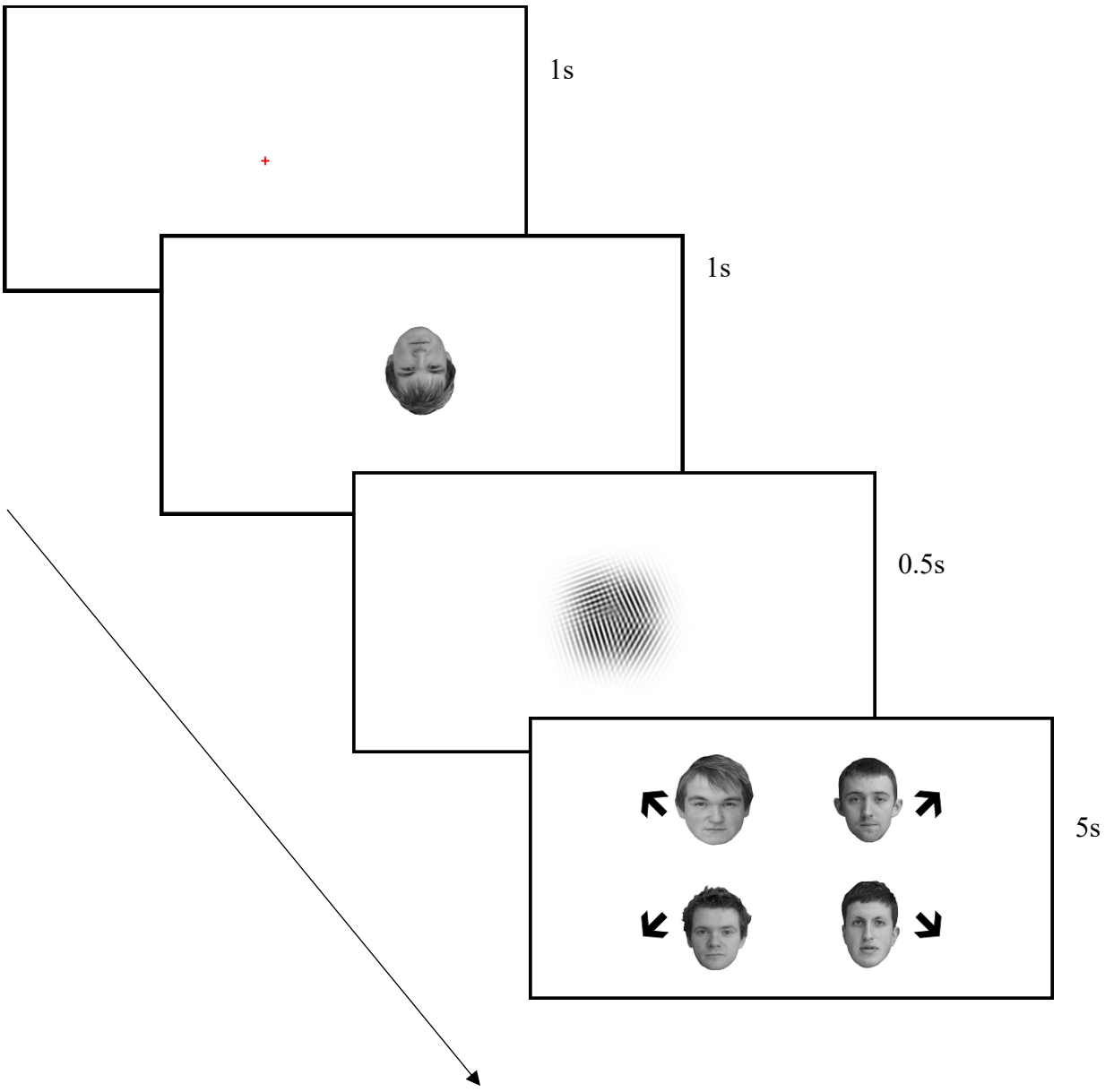


Example 2.

Appendix F

Face Matching Task

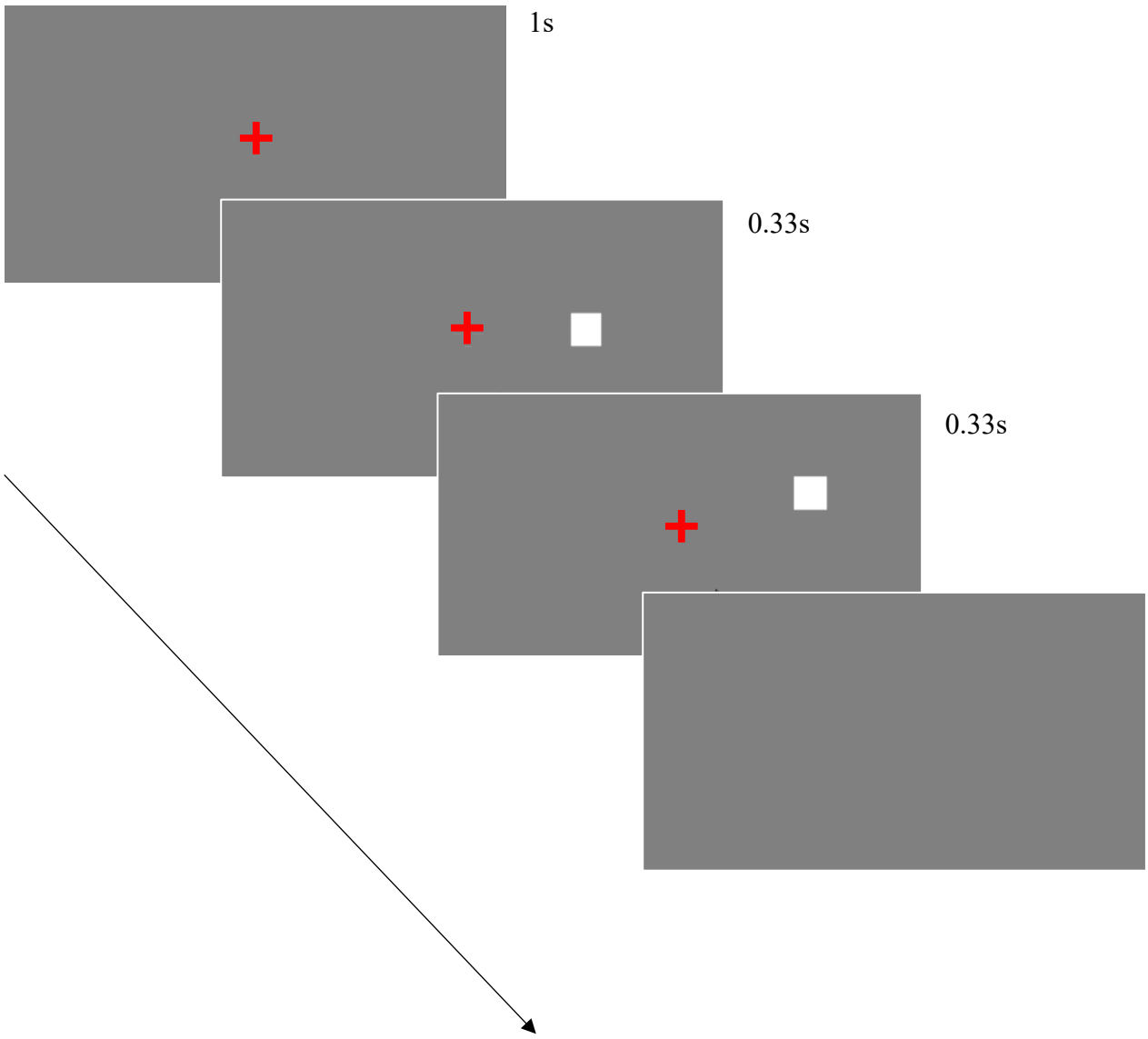
Central and inverted condition.



Appendix G

Apparent Motion Task

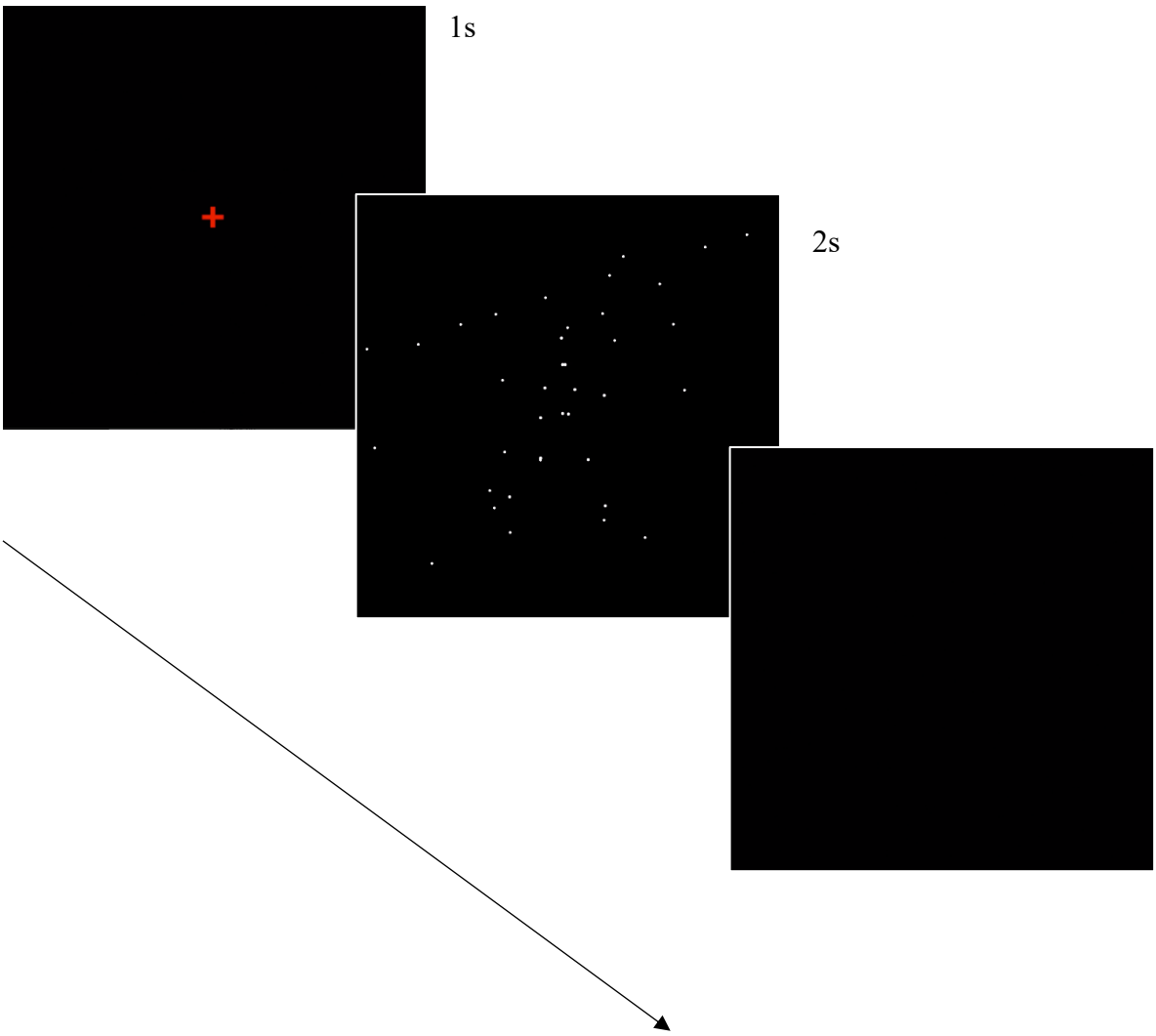
Peripheral condition.



Appendix H

Biological Motion Task

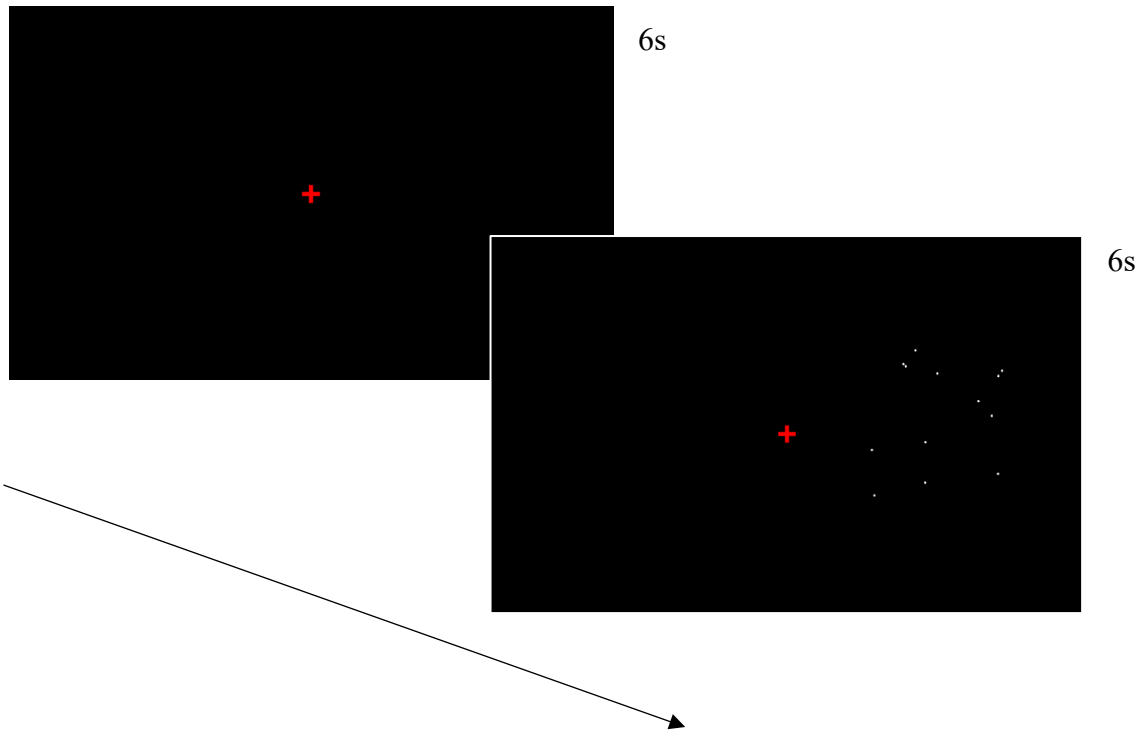
Central and upright condition.



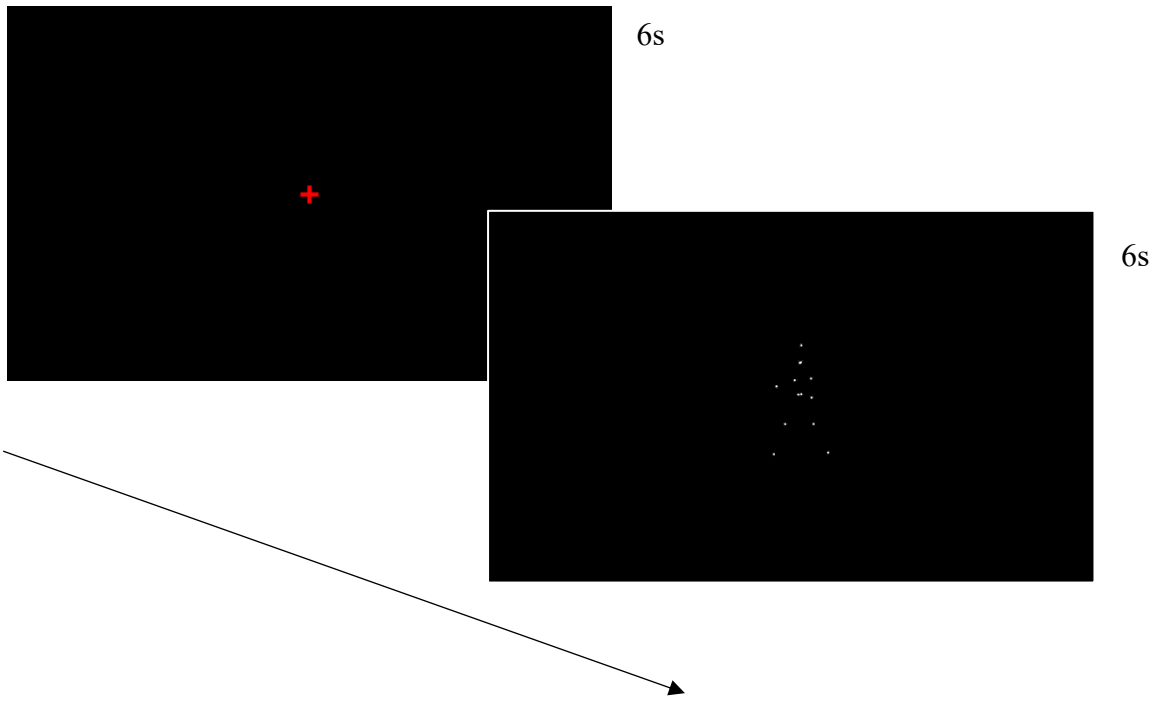
Appendix I

Motion Localizer

Scrambled dots presented in the right periphery.



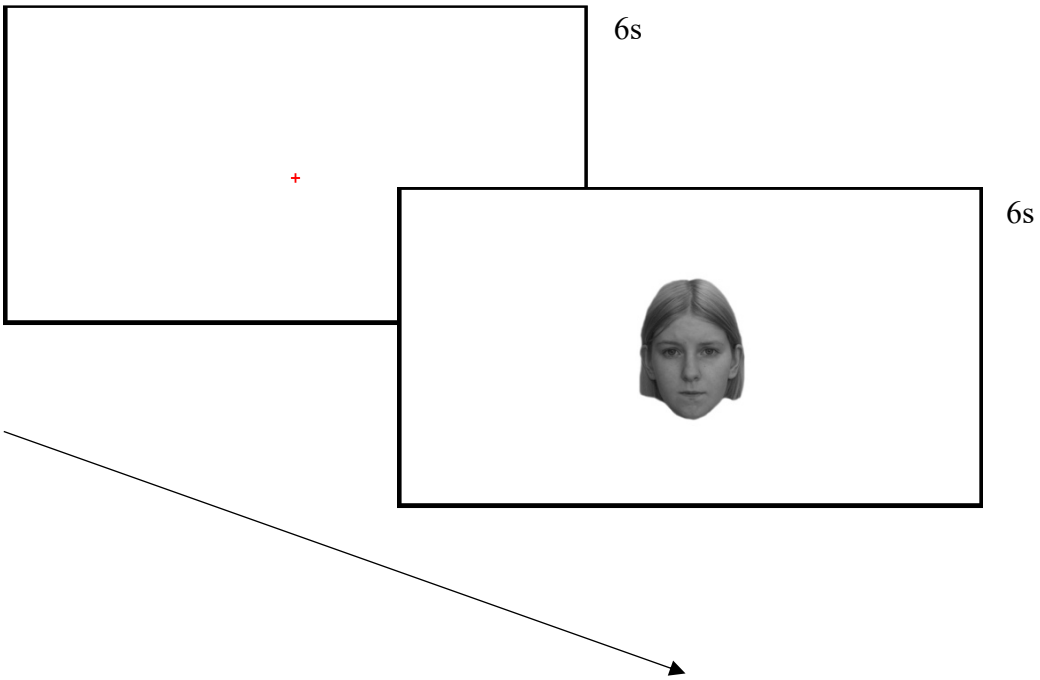
Point-light walker presented centrally.



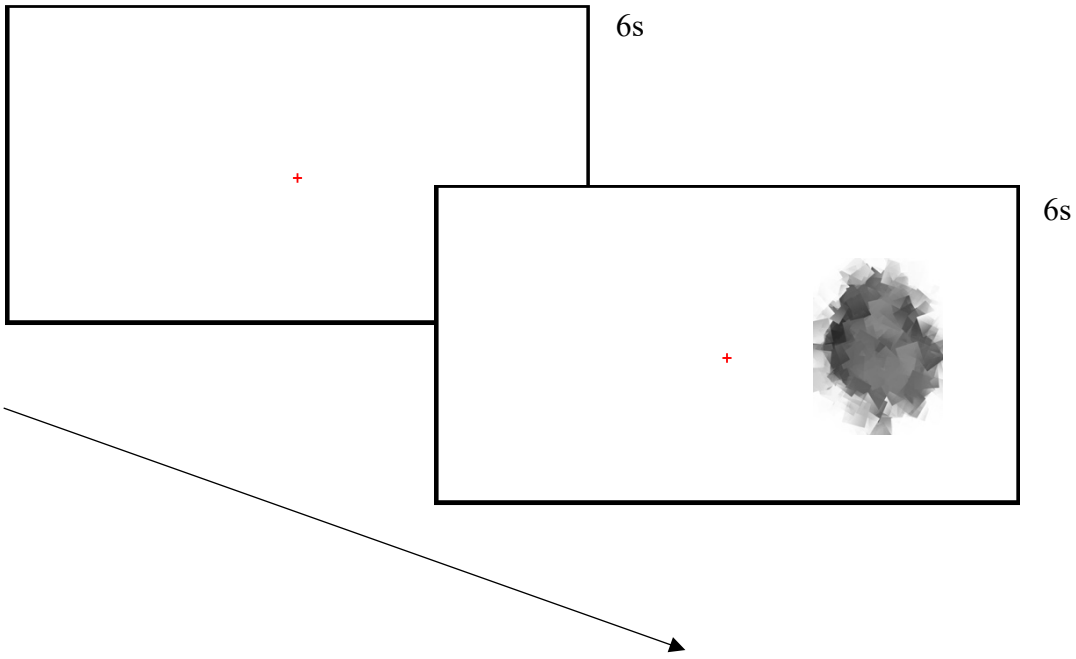
Appendix J

Face Localizer

Upright face presented centrally.



Scrambled face presented in the right periphery.



Appendix K

Letter of Information

Psychology

Project Title: Imaging Neural Function and Connectivity in the Deaf

Principal Investigator: Blake Butler, Ph.D.,
Department of Psychology | Brain and Mind Institute
The University of Western Ontario, WIRB 5150
(519) 661-2111 extension 85831
Email: bbutler9@uwo.ca

Introduction: Why you are here.

Dr. Blake Butler and his research team would like to invite you to participate in a study titled: "Neural Function and Connectivity in the Deaf. You are being invited to participate in this study because you are either a) an individual with no known hearing loss, or b) an individual with a self-reported hearing loss. This study is voluntary, and participation involves coming to Western on two occasions.

Background: What is the purpose of this study?

Dr. Butler and his team want to understand how the brain of people with hearing loss compensates and adapts to the loss of hearing, and how these changes influence the function of other sensory systems. Previous findings suggest that if an individual is deprived of hearing, the remaining senses become heightened. Some examples include, better performance in detecting visual events in the far-peripheral visual field, a better ability to distinguish differences in the direction of visual motion and faster reaction times in a number of visual tasks.

This study aims to investigate how changes in sensory processing are reflected in the brain, which brain regions contribute to these perceptual advantages, and how sensory regions communicate with each other, and to other brain regions that support cognitive functions like attention and memory.

Participate - If you want to take part in the study, you will be asked to take part in two (2) sessions. During your first visit, your hearing, sign-language proficiency, and non-verbal IQ will be assessed and you will complete a number of visual tasks in our laboratory, located within the Western Interdisciplinary Research Building at Western University. These tasks will include viewing brief visual stimuli on a computer screen and determining whether they differ in terms of duration, brightness, pattern, presence of motion, etc. These stimuli may be presented in isolation, or along with sounds. Throughout the session you will have the opportunity to take breaks. You will also be asked to fill out a simple questionnaire.

On the second visit, you will participate in a MRI brain imaging session, during which you may be asked to repeat a number of tasks from the first session while lying in a 3 Tesla MRI scanner. This part of the study will take place at the Robarts Research Institute at Western. You will be asked to lie comfortably within the scanner, remaining as still as possible, and to perform a series of visual tasks similar to those in first experimental session. You will make judgment about the visual stimuli and provide responses using a button-box that you will hold inside of the scanner. During these tasks, your brain activity will be recorded using Magnetic Resonance imaging, a non-invasive technique that does not involve injections, x-rays, or radiation. The MRI scanner will also be used to take structural images of your brain; during these scans you will not be required to perform a task.

The scanning session will proceed as follows:

- We will begin by completing a checklist to make sure that you can safely enter an MRI scanner.
- We will insert earplugs to protect your ears from the noise of the magnet.
- You will lie on your back on the scanner bed. Pillows will be placed under your legs for comfort and we will provide a blanket if you like. When ready, the bed will slide into the scanner.
- You will be asked to remain as still as possible while several images are taken, each lasting 5-8 minutes. We will place foam around your head to help minimize movement.
- The experiments in this session will be similar to those in the behavioral session, except that you will be asked to respond using a button box which you will hold inside of the scanner. Specific instructions will be given before each task.
- At some point during the session, additional brain images will be acquired of your brain anatomy. During these scans, you will be asked to lie as still as possible, but will not have to perform any tasks at this stage.

Thorough out the whole session, we will ask you to lie as still as possible, and speak to the MR technician from time to time. The total actual scanning will take approximately 60 minutes, while the entire visit will last approximately 1.5 hours from the time you arrive until the time you leave.

Voluntary Participation & Withdrawal

Your participation in this study is voluntary. You may elect not to participate at any time, including after the study has begun. You may leave the study at any time without affecting your compensation. If you no longer want to participate, or you do not want your data to be used in this research, you should tell either the experimenter that is with you in the room, or contact Dr. Butler (see contact information at the first page). They will ensure that your data as well as your personal information will be permanently deleted. If the data have already been analyzed as part of a group, it will no longer be possible to withdraw those results. However, your data will not be used future analyses. You can request withdrawal of your data until 7 years from data collection. After that time, it won't be possible to delete your data, as we will no longer know which data are yours.

Risks

This study involves a Magnetic Resonance Imaging (MRI) system, a common medical diagnostic tool that uses a strong magnetic field, a low frequency magnetic field, and a radio frequency field to take images of the brain. There are no known biological risks associated with MR imaging. Some people cannot have an MRI because they have some type of metal in their body. For instance, if you have a heart pacemaker, artificial heart valves, metal implants such as metal ear implants, bullet pieces, chemotherapy or insulin pumps or any other metal such as metal clips or rings, they cannot have an MRI. During this test, you will lie in a small closed area inside a large magnetic tube. Some people may get scared or anxious in small places (claustrophobic). An MRI may also cause possible anxiety for people due to the loud banging made by the machine

and the confined space of the testing area. You will be given either ear plugs or specially designed headphones to help reduce the noise.

Incidental Findings

As indicated above, the current study will involve a hearing-screening test. This is not a clinical measure, and the experimenters are not qualified to make a clinical diagnosis based upon these findings. Should a potential hearing deficit be suspected, you will be referred for audiological assessment by a trained professional.

The MRI scans carried out for this study are performed solely for scientific purposes. The data collected are not optimized to make clinical diagnoses and the research team involved in this experiment is not trained to make medical evaluations. By participating, you agree that the experimenters are not expected to arrive at a clinical interpretation of the data collected.

Nevertheless, there is a small possibility that a potential abnormality might be observed – otherwise known as an incidental finding. If this occurs, you will be notified of the issue by the principal investigator of the study who will assist you with your options for follow-up. Investigators are not responsible for the outcome of medical follow-up or for any incurred costs during medical follow-up. By participating, you agree to the possibility of being informed about a potential incidental finding, according to the above-described procedure. If you do not agree to the potential risk of an incidental finding, you should not participate in this study.

Benefits

There will be no direct benefit to you by participating in this study.

Confidentiality

As part of our data collection, you will be asked to provide your first name, phone number, email address, and full date of birth. These data will be kept apart from the experimental data, in a locked file cabinet in a locked laboratory. This information will not be shared with anyone outside of the research team*. The information collected from this study will be kept for a minimum of 7 years. De-identified data from this study will be made public online via the Open Science Framework and Open fMRI, which allow other researchers access to the de-identified data. The data that will be shared will not contain any information that could identify you. If you choose to withdraw from this study, your data will be removed and destroyed from all databases.

If you would like to be contacted about future research studies for which you may be eligible, you can choose to have your identifiable information entered into "OurBrainsCAN: University of Western Ontario's Cognitive Neuroscience Research Registry" by the researchers of this study OR alternatively you can be given the web address of OurBrainsCAN where you are able to enter your (or your child's) information. This is a secure database of potential participants for research at Western University, which aims to enrol 50,000 volunteers over a period of 5 years. The information in this database will be stored indefinitely. The records are used only for the purpose of recruiting research participants and will not be released to any third party. When you are invited to participate future research studies, you will be given a full description of what your involvement would entail. You are, of course, free to turn down any invitation. If, at any time, you decide that you do not want your contact information to be a part of this database, please contact ourbrains@uwo.ca to remove your information.

*Representatives of the University of Western Ontario Health Sciences Research Ethics Board may look at your study records at the site where these records are held, for quality assurance (to check that the information collected for the study is correct and follows proper laws and guidelines).

Costs & Compensation

You will not have to pay for any part of the study. Free parking will be provided. As a token of our appreciation for your participation in this study, you will receive $5 per 30 minutes of behavioural testing during the first experimental session and $15 per 30 minutes during the second session.

If you were recruited via the Western Psychology Participation Pool (SONA) you will be compensated 1 credit/hour of participation for both sessions.

Rights as a Participant

If you are harmed as a direct result of taking part in this study, all necessary medical treatment will be made available to you at no cost. You do not waive any legal rights by signing the consent form.

Questions about the Study

If you have any questions about the study, please contact:

Blake Butler, PhD
Department of Psychology | Brain and Mind Institute
The University of Western Ontario, WIRB 5150
(519) 661-2111 extension 85831
Email: bbutler9@uwo.ca

If you have any questions about your rights as a research participant or the conduct of this study, you may contact The Office of Research Ethics (519) 661-3036, email: ethics@uwo.ca.

This letter is yours to keep.

Appendix L

Consent Form

Your signature on this form indicates that you have read the letter of information, have had the nature of the study explained to you, and agree to take part in the study. You acknowledge that you can leave the study at any time.

_____	_____	_____
Print Name of Participant	Signature	Date
_____	_____	_____
Print Name of Person Obtaining Consent	Signature of Person Obtaining Consent	Date

I consent to being added to the OurBrainsCAN: University of Western Ontario's Cognitive Neuroscience Research Registry to be contacted about future research studies for which I may be eligible:

Please initial:

___ Yes, I already signed-up.
___ Yes, the researcher can enter my information into the database on my behalf.
___ Yes, please provide me the link to join the database myself.

Participant's Name (Please print):

Participant's Signature:

Date:

Appendix M

Debriefing Letter

Western
The Brain and
Mind Institute

Project title: Imaging Neural Function and Connectivity in the Deaf

Principal Investigator: Dr. Blake Butler

Thank you for taking part in this study. The purpose of these experiments is to better understand how the brain is able to adapt in hearing loss, by looking at the strength of connections between sensory processing regions of the brain, and how they communicate with each other.

We predicted that individuals with hearing loss would show advantages in visual tasks which involve detecting events in the peripheral visual field. Alongside these advantages, we also predicted that stronger connections would be present between intact sensory regions when compared to individuals with normal hearing, and that these differences underlie this increased sensitivity in visual perception.

Here are some references if you would like to read more on the topic:

Bavelier, D., Dye, M. W., & Hauser, P. C. (2006). Do deaf individuals see better?. Trends in cognitive sciences, 10(11), 512-518.

Shiell, M. M., Champoux, F., & Zatorre, R. J. (2014). Enhancement of visual motion detection thresholds in early deaf people. PLoS One, 9(2), e90498.

Hauthal, N., Sandmann, P., Debener, S., & Thorne, J. D. (2013). Visual movement perception in deaf and hearing individuals. Advances in cognitive psychology, 9(2), 53.

Thank you,

Dr. Blake Butler and his research team
Department of Psychology | Brain and Mind Institute
The University of Western Ontario, WIRB 5150
(519) 661-2111 extension 85831
Email: bbutler9@uwo.ca

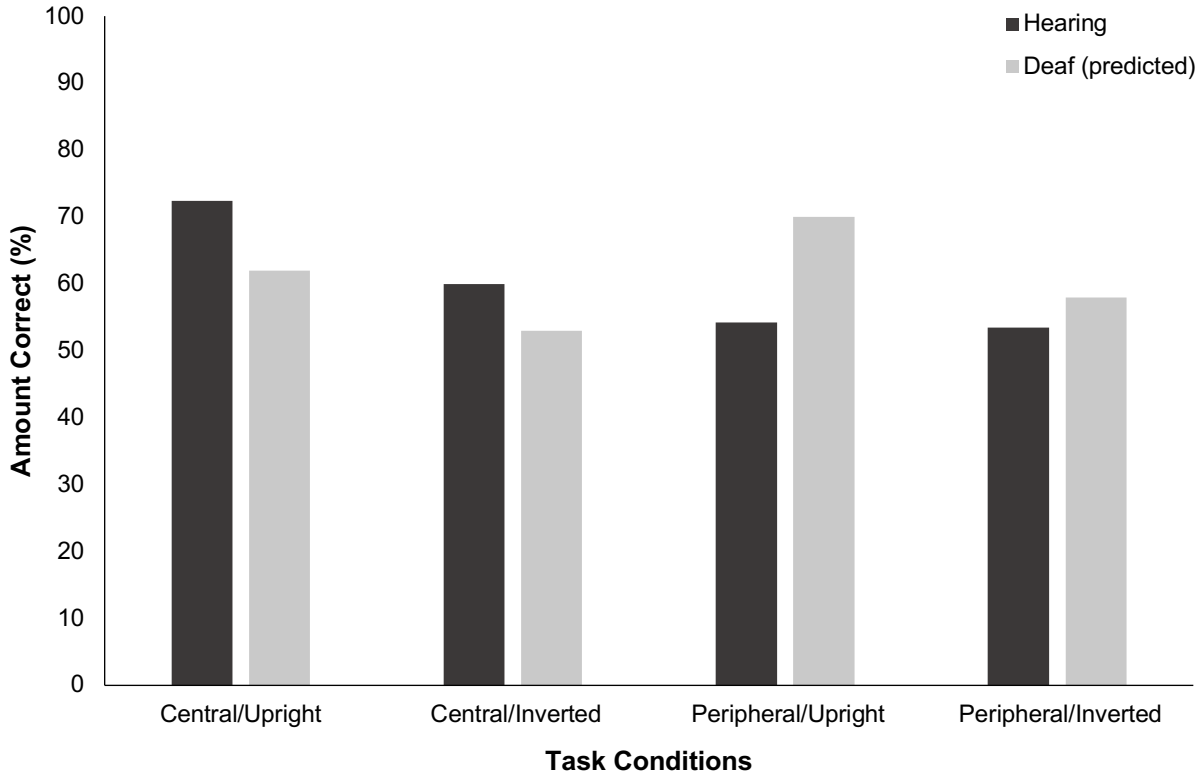


Figure 1. Face matching accuracy for hearing controls. Predicted data shown for deaf participants in light grey.

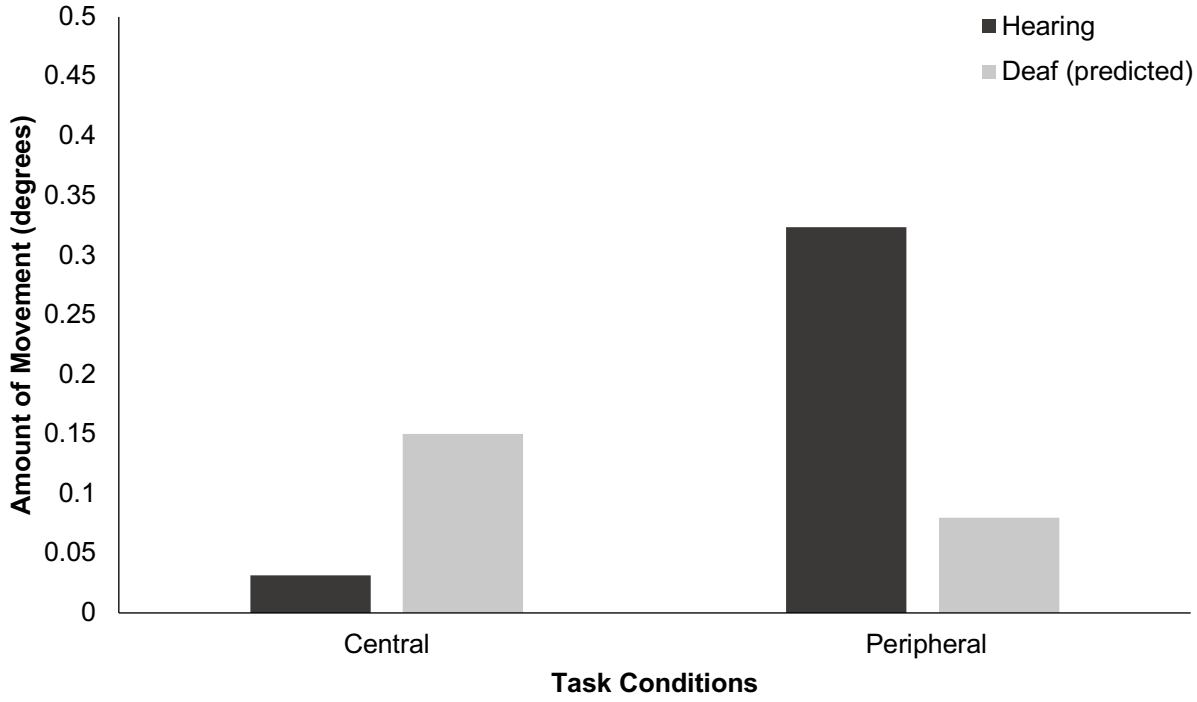


Figure 2. Non-biological (apparent) motion detection thresholds. Thresholds converge at the 77.85%-correct points. Predicted data shown for deaf participants in light grey.

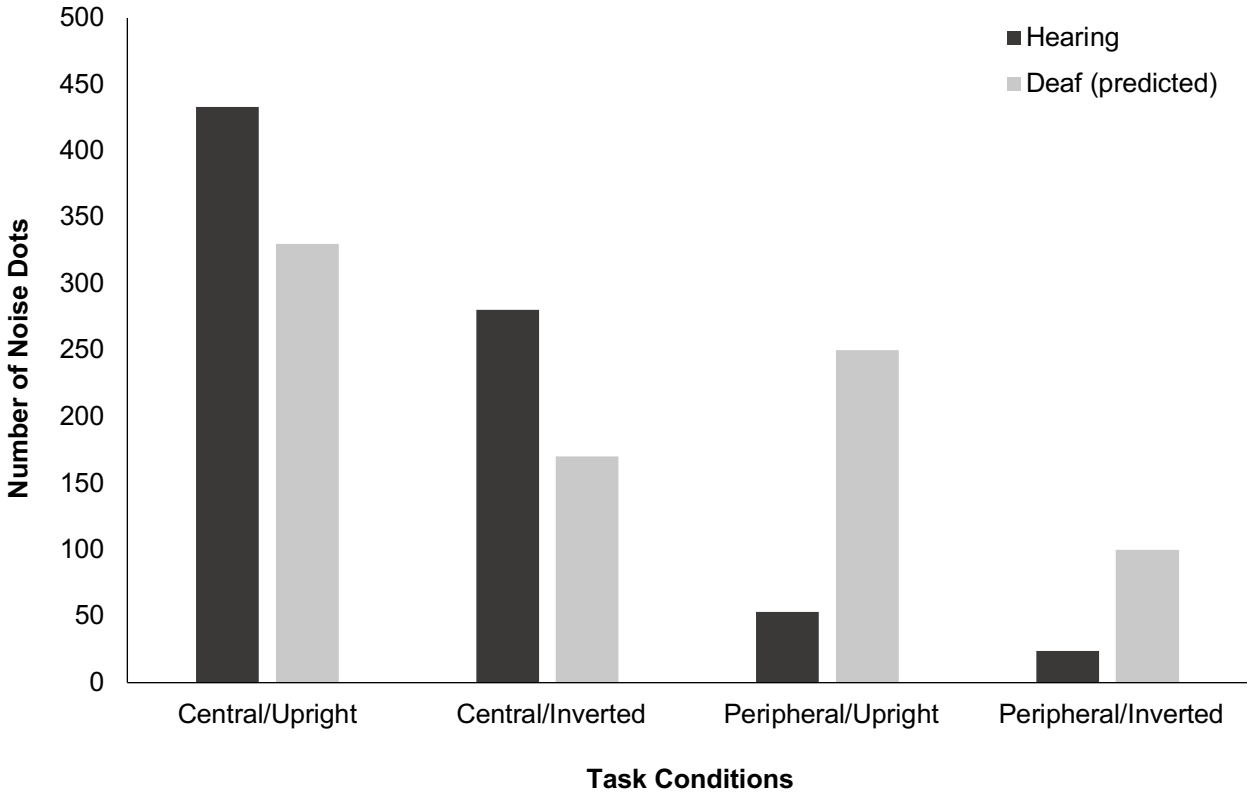


Figure 3. Biological motion detection thresholds. Thresholds converge at the 77.85%-correct points. Predicted data shown for deaf participants in light grey.

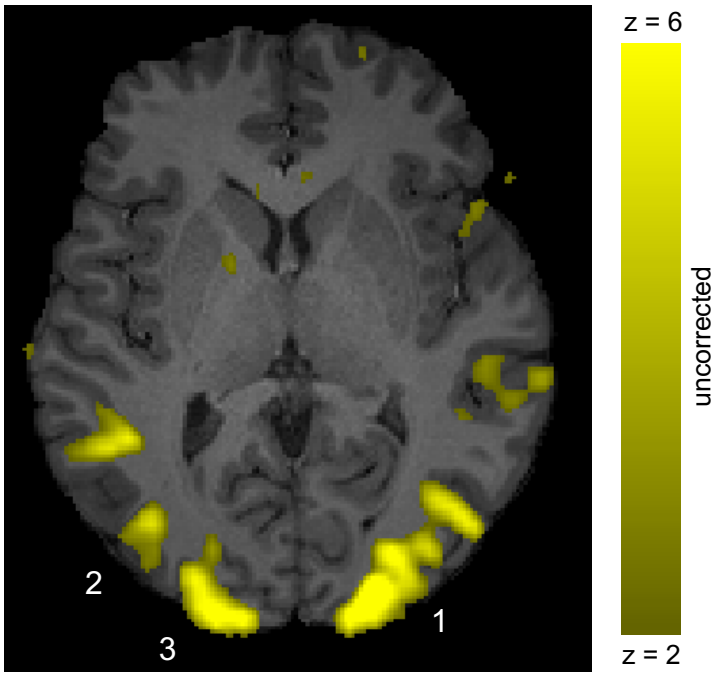


Figure 4. All central face presentations (intact, scrambled) shown over rest. Clusters significant at $p < .05$. (1) MNI (47.7, -85.6, -12.3); 7% right LOC-inferior. (2) MNI (-43.5, -79.5, -7.86); 77% left LOC-inferior. (3) MNI (-17.9, -101, 8.87); 68% left occipital pole.

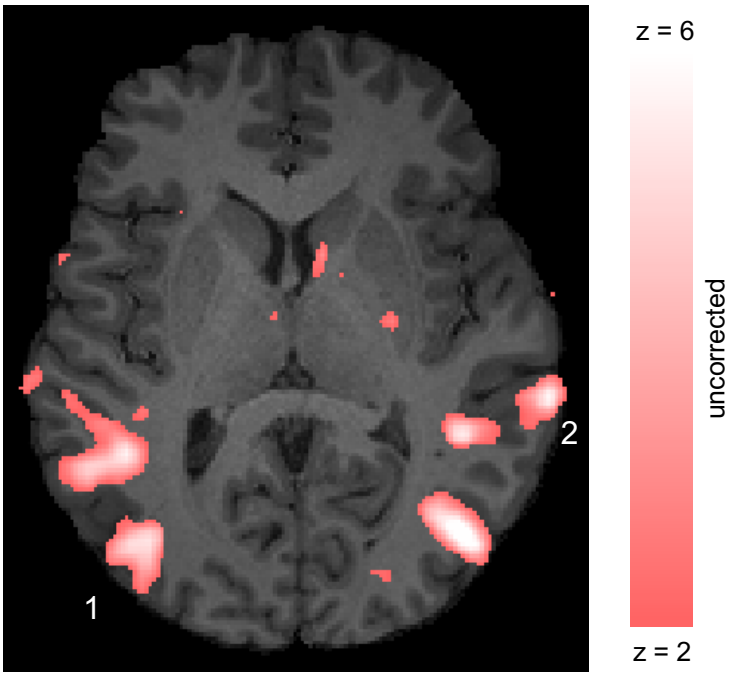


Figure 5. All peripheral face presentations (intact, scrambled) shown over rest. Clusters significant at $p < .05$. (1) MNI (-44.3, -78.6, -8.01); 75% left LOC-inferior. (2) MNI (70, -35.3, 10.5); 20% right STG, 11% right SMG, 6% right MTG.

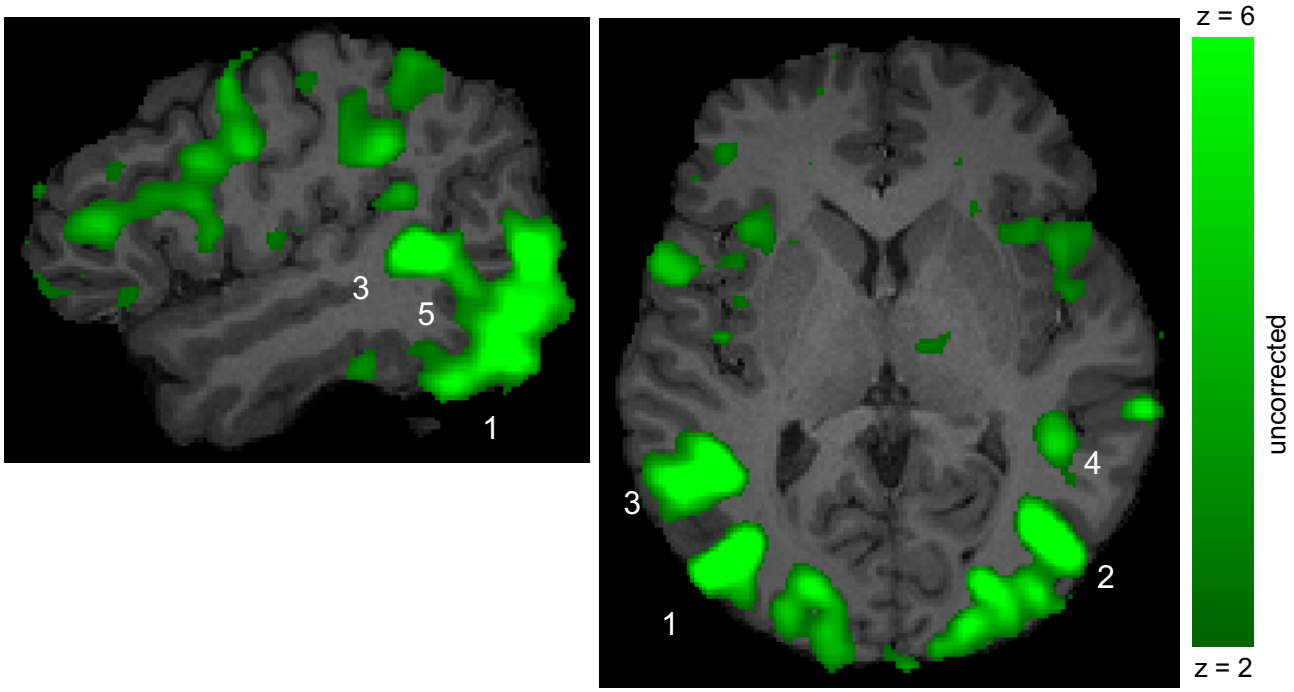


Figure 6. All motion (biological, non-biological) shown over rest. Clusters significant at $p < .05$. (1) MNI (-44.4, -73.4, 12.1); 55% left LOC-inferior, 21% left LOC-superior. (2) MNI (41.1, -65, 1.97); 23% right LOC-inferior, 7% right MTG. (3) MNI (-43.4, -49.5, 9.16); 11% left LOC-superior, 6% left precuneus cortex, 4% left angular gyrus. (4) MNI (-25.5, -69.8, 21.7); 53% right LOC-superior, 3% right precuneus cortex. (5) MNI (70.2, -35, 10.4); 14% left MTG, 8% left SMG.

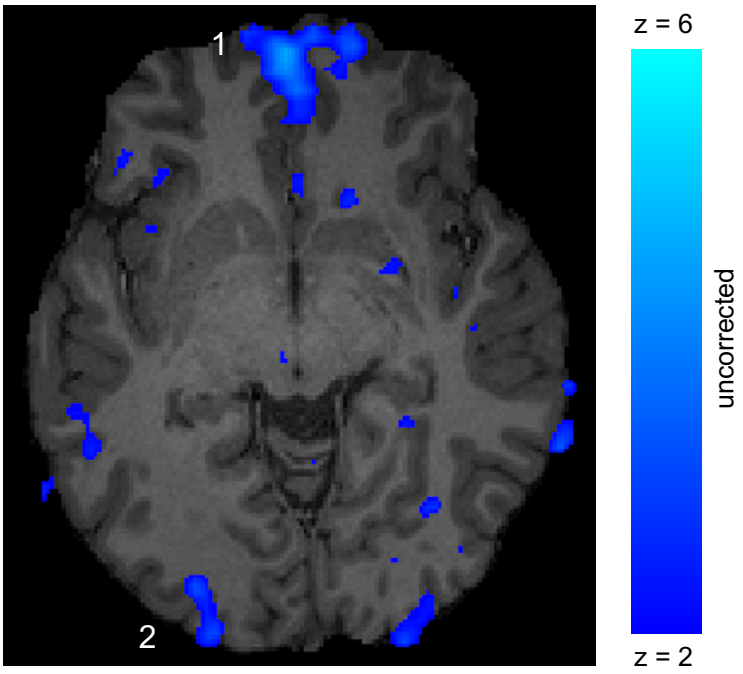


Figure 7. Biological motion shown over motion. Clusters significant at $p < .05$. (1) MNI (-2.06, 56.6, -12.4); 68% left frontal pole, 22% left frontal medial cortex. (2) MNI (-33.6, -93.3, -8.59); 51% left occipital pole, 26% left LOC-inferior.

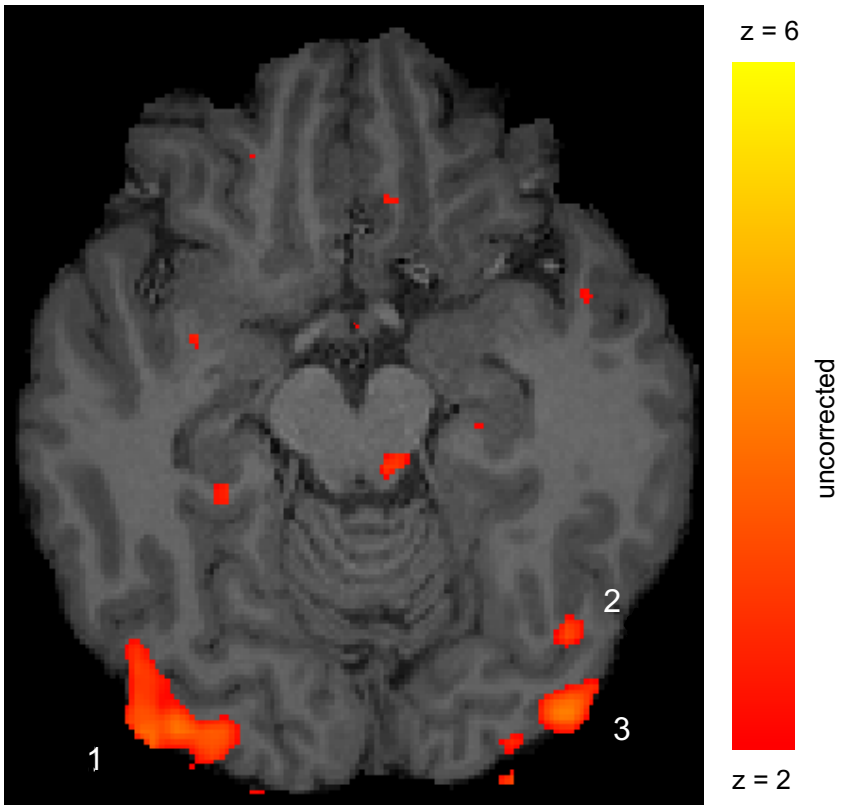


Figure 8. Intact faces shown over scrambled faces. Clusters significant at $p < .05$. (1) MNI (-45.2, -75.5, -15.2); 62% left LOC-inferior, 17% left occipital fusiform gyrus. (2) MNI (40.5, -47.4, -29.1); 2% right temporal occipital fusiform cortex. (3) MNI (44.9, -88.3, -8.43); 22% right LOC-inferior, 8% occipital pole.