**Title:**

Somatosensory Response Changes During Illusory Finger Stretching

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**Abstract**

Resizing illusions, delivered using augmented reality, resize a body part through either stretching or shrinking manipulations. These resizing illusions have been investigated in visuotactile, visual-only and visuo-auditory presentations. However, the neural underpinnings of these resizing illusions remain undefined. This study seeks to understand the neural mechanisms behind these illusions in healthy participants, by using somatosensory steady state evoked potentials in addition to subjective self-report questionnaires, to enhance knowledge of what drives the subjective embodiment during resizing illusions. Resizing Illusions have been shown to provide analgesic effects for individuals with chronic pain conditions, therefore, this study also aims to provide an empirical basis for later investigations in chronic pain samples undergoing resizing illusions. [results and conclusions to be added].

***Key Words:*** Somatosensory Evoked Potentials, EEG, Resizing Illusions

1. **Introduction**

Illusory finger stretching is a form of multisensory illusion, specifically a resizing illusion, which alters the subjective perceptual experience of the size of one’s finger. Resizing illusions, through changing the way in which a body part is perceived, exploit principles of multisensory integration to elicit modulations in the perceived size and shape of the body (Preston & Newport 2011; Preston et al., 2020; Stanton et al. 2018). Resizing illusions are based on the rubber hand illusion, in which touch is delivered to a visible fake hand at the same time and in the same place that touch is delivered to the hidden real hand. This manipulation elicits feelings of ownership over the fake hand through the integration of multisensory (tactile and visual) inputs highlighting the apparent malleability of bodily self (Botvinick & Cohen, 1998). Multisensory resizing illusions typically involve both tactile and visual inputs to the participant and can be delivered via an augmented reality system or through magnifying optics. Recent studies have also shown resizing illusions to be effectively administered through visual only, and visuo-auditory manipulations (Schaefer et al., 2007; Tajadura-Jiménez et al., 2017). However, multisensory visuotactile manipulations are reported as the most effective at inducing a strong experience of the illusion within an augmented reality system (Hansford et al., 2023a).

The augmented reality system used to deliver these resizing illusions presents real-time video capture of the hand, from the same position and perspective as if the hand were being viewed directly (Preston & Newport, 2011). This allows the experimenter to deliver tactile manipulations, such as gently pulling or pushing the hand/finger, whilst the participant views their hand/finger either stretching or shrinking in the augmented image. Newport, Pearce and Preston (2010) found strong embodiment using a synchronous multisensory visuotactile illusion, which was replicated in our pilot data using the same experimental set up as the current study, showing, although not significant, a numerically greater illusory experience during synchronous visuotactile manipulations compared to asynchronous (mismatching visuotactile manipulation) control conditions (Appendix B) for illusory finger resizing. When comparing multisensory visuotactile resizing illusions to unimodal visual resizing illusions, our recent work (Hansford et al., 2023a) shows that multisensory illusions elicit significantly greater illusory experience compared to non-illusion and unimodal visual illusion conditions in healthy participants. We also showed, in exploratory analysis, that a subset of participants who experienced an illusion in the unimodal visual condition reported a stronger illusory experience in this condition than in an incongruent (mismatching visual and tactile inputs) control condition. This subset analysis, however, was of a small sample size, and was selected based on one of the measures analysed thus should be taken with caution, meaning further replication of the findings are needed. Furthermore, we have demonstrated that a visuo-auditory presentation of the finger resizing illusion, using non-naturalistic auditory input, provides a stronger illusory experience than a visual only presentation, but this does not surpass the illusion strength given by a visuo-tactile illusion (Hansford et al., 2023b).

Neuroimaging has previously been used in healthy populations experiencing resizing illusions, whereby modulation of the primary somatosensory cortex has been found using neuromagnetic source imaging during visual only resizing illusions of the arm (Schaefer et al., 2007). Briefly, the more the subjects felt the subjective experience of an elongated arm, the more the cortical distance between the first and fifth digit decreased, showing the topographical representation of the somatosensory cortex being modulated by perceived location of a stimulus. Specifically looking at stretching multisensory visuotactile illusions, which as mentioned are those that elicit the greatest illusion strength in a majority of participants, recent research suggests that these illusions impact the neural representations of the body and reflect early-stage multimodal stimulus integration through modulation of gamma band activity (Kanayama et al., 2021). We have recently also investigated this illusion in healthy participants using electroencephalography (EEG) and have found support for this previous research, finding significant increases in gamma band power, likely reflecting multimodal stimulus integration, in multisensory visuotactile compared to unimodal visual conditions during illusory resizing of a finger (Hansford et al., 2023a). Previous research using rubber hand illusions found this multisensory integration effect in early-stage gamma band increases (Kanayama et al., 2021), whilst our recent findings show a later stage of multimodal stimulus integration when using illusory finger resizing manipulations (Hansford et al., 2023a).

Looking specifically at research into somatosensory cortex modulation using steady-state evoked potentials (SSEPs), low-level somatosensory responses have been induced directly using vibrations of a known frequency applied to a body part. These generate a frequency-locked steady-state evoked potential detectable at the scalp using EEG (Snyder, 1992; Tobimatsu et al., 1999), and are an index of the cortical response to a stimulus. This paradigm has been used with other sensory modalities to better understand the neural mechanisms underlying multisensory integration, with findings showing that presentation of temporally congruent auditory and visual stimuli significantly enhances the magnitude and inter-trial phase coherence of auditory and visual steady-state responses (Nozaradan et al., 2012). Research has also found evidence of enhanced steady-state responses for within-modality stimulation of auditory and visual stimuli in isolation (Giani et al., 2012), complementing Nozaradan et al.’s findings regarding visuo-auditory combination. Research using vibrotactile stimulation has found increases in steady-state response magnitude corresponding with the amplitude modulation rate of stimulation (Colon et al., 2012; Rees et al., 1986) suggesting an entrainment of oscillatory activity to temporal features of sensory stimulation (Timora & Budd, 2018). Given these findings, we anticipate that somatosensory steady-state signals might change during finger resizing illusions, due to the multisensory manipulations present, to give a potential index of changes in neural representations during the illusion.

Several studies have investigated the analgesic effect of these resizing illusions, as they have been shown to reduce chronic pain in conditions such as osteoarthritis (Preston & Newport, 2011; Preston et al., 2020; Stanton et al., 2018), chronic back pain (Diers et al., 2013), and complex regional pain syndrome (Moseley, Parsons & Spence, 2008). However, the understanding of how these illusions reduce pain is still undetermined. It has been suggested chronic pain involves cortical misrepresentations of the size of the affected body part (Boesch et al., 2016), however, it is unknown if resizing illusions affect this cortical misrepresentation, and if this is therefore what causes the reduction in pain. No study has yet used neuroimaging with a chronic pain population to determine the cortical activity correlated with this illusory analgesia. However, importantly, there has also not been research conducted using somatosensory steady state evoked potentials (SSEPs) in healthy participants, to understand what the cortical representations of these resizing illusions are like without the impact of a chronic pain condition. Therefore, the aim of this study is to examine potential changes in the somatosensory cortex during illusory finger resizing in healthy participants, using vibrotactile SSSEPs, to use as a basis for later investigations in a sample of chronic pain participants. If we can identify a link between illusory resizing and somatosensory cortex changes, this will enhance our understanding of what is happening in the brain during these illusions and will act as a reference for comparison with neural representations in individuals with chronic pain conditions.

Using different sensory manipulations of finger resizing illusions, in addition to using an electromagnetic solenoid stimulator, this study aims to investigate subjective illusory experience and SSEP responses in healthy participants, to better understand the experience of body ownership illusions from subjective experience and cortical representation perspectives. To test this, different finger resizing illusions consisting of multisensory (visuotactile) stretching (MS), unimodal-visual stretching (UV), a non-illusion control condition without tactile input (NI), and a non-illusion control condition with tactile input (NIT) will be used to assess alternate aspects of illusory resizing manipulations and their related effects on SSEP response. The inclusion of two control conditions (NI, NIT) is to assess whether localisation of cortical representations arise from resizing manipulations to the finger, or from tactile input given to the finger. The first hypothesis, acting as a positive control (1), is that there will be a greater illusory experience, measured via a subjective illusory experience questionnaire, in the MS condition compared to the NI and NIT conditions. The main experimental hypothesis for this study is that (2) there will be a significant difference in SSEP response across the electrodes of interest (F1 & FC1, see section 3. Pilot Data) when comparing across all conditions. Subsequent hypotheses are that there will be significant differences in SSEP response when comparing (2a) MS visuotactile illusory resizing to the NI condition, when comparing (2b) UV illusory resizing to the NI condition, and (2c) that there will be no significant difference when comparing the NIT condition to the NI condition.

1. **Methods**
   1. *Sample Size*

Overall, based on the power analyses in section 2.5, a total sample size of 30 participants will be tested. This sample size adheres to the higher end of sample size estimates (Hypothesis 2 (2.5.2) showing 30 participants needed).

*2.2 Participants*

Ethical approval for this research was gained from the Department of Psychology, University of York (ethics application code 950), in line with the Declaration of Helsinki. Informed consent from each participant will be gained prior to the start of any experimental set up, and participants will be instructed that they can withdraw their participation at any time during or after completion of the experiment.

Sample inclusion / exclusion criteria:

Inclusion and exclusion criteria will be determined using self-report responses relating to each item listed below:

* Inclusion Criteria: Right-handed, 18 years of age or over, no older than 75 years of age (include those aged 75 years).
* Exclusion Criteria: Prior knowledge or expectations about the research, a history of developmental, neurological or psychiatric disorders, history of drug or alcohol abuse, history of sleep disorders, history of epilepsy, having visual abnormalities that cannot be corrected optically (i.e. with glasses), or being under 18 years of age, or over 75 years of age. A history of chronic pain conditions, operations or procedures that could damage peripheral nerve pathways in the hands, current experiences of pain or more than 4 hours of consistent pain experienced in the preceding week.

Raw data exclusion criteria:

* Less than 100% of the experiment completed by a participant, more than 50% of electrodes for a single participant requiring removal from EEG data, or if both electrodes F1 and FC1 (electrodes of interest) require removal. More information about data removal can be found in section 2.4.1 Preprocessing Steps.

*2.3 Experimental Procedure*

All participants will complete a demographic survey, asking their age and sex, and will be asked to complete the revised Waterloo Handedness Questionnaire (WHQr) (Elias et al., 1998). The WHQr self-reported handedness questionnaire consists of 36 questions. The questions are answered on a 5-level, Likert scale to determine the degree of preferred hand use, with left always being -2, left usually being -1, equal use being 0, right usually being 1 and right always being 2. The sum of the total WHQr score can then be used to categorise a respondent as left-handed (score of -24 or less), mixed handed (score of -23 to +23), or right-handed (score of +24 or higher). Only participants who are categorised as right-handed will continue participation.

Participants will then be set up with an appropriately sized 64-channel EEG cap with electrodes arranged according to the 10/20 system. The experimenter will use conductive gel to make a conductive bridge between the electrodes and the scalp to attempt to obtain impedance levels of <10kΩ per electrode. The whole head average will be used as a reference.

Diagram

Description automatically generated*Figure 1*. Schematic of Augmented Reality System with Tactile Stimulator.

Participants will then be seated behind the augmented reality system (Figure 1) and instructed to place their hand onto the black felt fabric within the augmented reality system. Within the self-built system there is a 1920 x 1080-pixel Spedal Webcam Wide Angle Camera at the edge of the black felt on the side the participant sits, away from the participant’s view. 26cms above the felt base, there is a mirror, which is placed 26cms below a screen with a resolution of 1920 x 1200 pixels, with a width of 52cms and a height of 32cms. The thickness of section on which the mirror sits is 2cms. This screen is 54cms from the base of the system, and the base of the system is 82cms from the ground. Participants will be instructed to place either their right index or middle finger outstretched onto the felt. The decision of whether the participant will use their index or middle finger will be pseudo randomised (to give equal representation of each finger) via MATLAB prior to any participants taking part. There will be two white dots for each hand on the felt and participants will be instructed to place their hand between these two dots. Participants will be instructed to view their hand’s image in the mirror (the real hand will be hidden from view) throughout the experiment. The camera placed underneath the mirror on the felt base will be used to deliver a live feed video of the participant’s hands to the computer screen at the top of the augmented reality system, which will show in the mirror reflection to the participants. There is a delay of 170ms in the video processing pipeline from the camera image to the augmented video image.

Participants will undergo 4 conditions: multisensory stretching (MS), unimodal-visual stretching (UV), a non-illusion control condition without tactile input (NI), and a non-illusion control condition with tactile input (NIT). There will be vibrotactile stimulation to the finger in all conditions, but only tactile input of the researcher touching the participants hand in the conditions where this is mentioned. Each trial will last 2.4 seconds for the manipulation phase, where the finger will be stretched by 60 pixels (2.1 centimetres) in UV and MS conditions, followed by a further 2.4 second habituation phase in which participants can view and move their (augmented) finger, whilst they keep the rest of their hand still, before the screen goes dark, indicating that the next trial can start. The MS condition consist of the researcher touching and pulling the participant’s finger as the participant views their finger stretching in a congruent manner. The UV conditions consists of the participants viewing their finger stretch without any experimenter manipulation. The NI condition provides no visual or touching tactile manipulations to the finger. The NIT control condition will involve no visual input of the finger stretching, instead the image of their finger will be visible but unchanged. Additionally, this condition will include tactile input of the experimenter’s hand touching the participant’s finger, but without pulling. Visualisation of all conditions can be seen in Figure 2.

*A hand with a finger pointing to the right

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*Figure 2*. Infographic of Experimental Conditions. MS = Multisensory Stretching, UV = Unimodal Visual Stretching, NIT = Non-Illusion Tactile, NI = Non-Illusion. During the manipulation phase (2.4 seconds) the visual image of the finger is stretched in the MS and UV conditions, and/or the experimenter provides tactile input (touch) in the MS and NIT conditions. The tactile input in the MS condition is accompanied by pulling. During the habituation phase (2.4 seconds) participants are free to move their finger. The arrow denotes the direction of the experimenter’s action. The vibrotactile stimulator is depicted on the finger in each phase of the experiment as vibrations are presented throughout.

The experimenter will be seated opposite the participant, the other side of the augmented reality machine and will touch the digit during MS and NIT conditions by holding onto the distal interphalangeal joint and gently touching (NIT) or pulling (MS) the finger whilst the participant keeps their hand in place. Conditions will be delivered across 4 blocks, with each block consisting of 24 trials of the same experimental condition, totalling 96 trials over all 4 blocks. The ordering of the blocks will be randomised for each participant to prevent ordering effects. The experiment will be programmed in, and the conditions randomised using MATLAB R2017a and the experimenter will be informed of whether to pull the finger or to touch the finger via an indicative box displayed on the screen out of the participant’s view. If the box is blue, this will indicate a need to pull the finger, if it is white it will indicate a need to touch the finger, if there is no box displayed then this indicates no tactile manipulation from the experimenter. The researcher will use a button press to trigger the start of the manipulation, and will start pulling the finger, when needed, synchronously within the 2.4 second manipulation phase.If the experimenter forgets to pull the finger on a multisensory condition, or mistakenly pulls the finger in a control trial, then this will be noted during the experiment, and that trial will be removed from analysis. Vibrations will be delivered to the participant’s finger in all conditions using a miniature electromagnetic solenoid stimulator (Dancer Design Tactor; diameter 1.8mm) emitting vibrations produced by sending amplified 26Hz sine wave sound files, with stimulus intensity controlled by an amplifier (Dancer Design TactAmp). The tactor is driven at 50% of the maximum (i.e. a peak input voltage of 3V) using a 26Hz sine-wave, and delivers a peak force of 0.18N. The electromagnetic solenoid stimulator will be attached to the participant’s finger that is outstretched and will receive the manipulations, between the knuckle and the first finger joint, using a black Velcro strip and will give continuous stimulation for the duration of each trial. Participants will be encouraged to take a break between each of the blocks to stretch their hand. EEG will be recorded throughout as a continuous recording with conditions denoted by numbered 8-bit digital at the start of each trial (USB-TTL Module, Black Box Toolkit Ltd.).

Finally, at the end of each block, the participant will be asked to complete the subjective illusory experience questionnaire regarding a condition presented in a given block using the Samsung Galaxy Tab A6 tablet via a questionnaire on Qualtrics (Qualtrics, Provo, UT). The questionnaire consists of six questions relating to the trials the participant had just experienced. Two statements relate to illusory experience: “It felt like my finger was really stretching” / “It felt like the finger I saw was part of my body”, two relate to disownership: “It felt like the finger I saw no longer belonged to me” / “It felt like the finger I saw was no longer part of my body”, and two are control questions: “It felt as if my finger had disappeared” / “It felt as if I might have had an extra finger” (all questions will be directed towards the participants manipulated finger*)*. Control questions are included to create an index for the illusion and disownership questions (more detail can be found in section 2.4.1 - Preprocessing steps), whilst disownership questions are included to assess if the potential experience from the illusions results from a disownership of the body part, or from subjective embodiment of the body part (McCabe, 2011). A visual analogue scale from 0 – 100 will be used for each statement, with 0 being strongly disagree, 50 being neutral and 100 being strongly agree.

Data collection will be terminated when the full sample of participants have been tested. If a participant completes <100% of the experiment or if over 50% of electrodes need removal, or if either electrode F1 or FC1 needs removal, then their data will not be included, and additional participants will be recruited to replace any lost data.

*2.4 Analysis Pipeline*

2.4.1 Preprocessing steps

Data will first be converted using MATLAB and EEGlab from the ANT EEprobe .cnt format to EEGlab .set format. All subsequent analysis will then be conducted using the MNE-Python toolbox (Gramfort et al., 2013). A 50Hz notch filter will first be applied to the raw EEG data for all electrodes, followed by calculation of the standard error across time for each electrode for each participant (Luck et al., 2021). Across the standard errors for all participants, the 5% of electrodes showing the largest standard errors will be used to create a standard error threshold. Any electrode with a standard error above this threshold, or with a value of 0, will be removed from analysis. Where a participant has over 50% of their electrodes over the standard error threshold or with a value of 0, or if the electrodes requiring removal contain both electrodes F1 and FC1 (electrodes of interest), then their data will be removed. Primary analysis of the remaining EEG data will then involve averaging the signal across the electrodes of interest (F1 and FC1), and calculating the Fourier transform for each trial per participant. These amplitudes will then be averaged across trials to give overall results for each participant. Statistical comparisons will then be performed on the Fourier amplitudes at the stimulation frequency (26Hz), across conditions and participants. No additional filtering or denoising steps will be applied to the EEG data, in line with Figueira et al.’s (2022) report that only a Fourier transform is typically needed for this type of EEG data.

Regarding questionnaire data, scores for both illusion experience questions will be combined to give median scores, along with both disownership questions and both control questions, resulting in 3 median scores per trial per participant. The median control scores will be used to create an index of the illusion and disownership scores by subtracting the median control score from the median illusion and median disownership scores, in line with previous research doing similarly (Matsumiya, 2021; Kilteni & Ehrsson, 2017; Kalckert & Ehrsson, 2012). The normalised (baseline corrected) data will be used for analyses, with a new scale from -100 to +100 with 100 indicating strongly agree, 50 indicating a neutral opinion, and scores below 0 indicating strongly disagree with the statements on the questionnaire.

2.4.2 Planned analyses

2.4.2.1 Hypothesis 1 (Positive Control)

*(1 – Positive Control) There will be a greater illusory experience, measured via a subjective illusory experience questionnaire, in the MS condition compared to the NI and NIT conditions.*

The subjective illusory experience questionnaire will be used as a positive control for the current study. Previous research has shown significantly greater illusion strength for MS conditions compared to non-illusion conditions (Carey et al., 2019; Hansford et al., 2023a), which we will attempt to replicate. Questionnaire data will be analysed using R (R Core Team, 2021). A one-way ANOVA will be run to compare the dependent variable of normalised (baseline corrected) illusion score from each independent condition. Given significant findings, post-hoc tests will be run, with Bonferroni correction for 2 comparisons (MS Vs NI, MS Vs NIT) at an initial alpha of 0.05.

Interpretations for hypothesis 1 can be found in the design table (Appendix A).

2.4.2.2 Hypothesis 2

*There will be a significant difference in SSEP response across the electrodes of interest (F1 & FC1) when comparing (2a) the MS condition to the NI condition, when comparing (2b) the UV condition to the NI condition, and (2c) that there will be no significant difference when comparing the NIT condition to the NI condition.*

As mentioned in the EEG pre-processing steps in section 2.4.1, analysis of EEG data will involve taking a Fourier transform for each waveform averaged across the electrodes of interest, to obtain the amplitude for each trial at the vibration frequency (26Hz). These amplitudes will then be averaged across trials to give overall results for each participant, before running a repeated measures one way ANOVA comparing SSEP response from each experimental condition. The dependent variable will be SSSEP amplitude in µV, whilst the independent variable will be the different manipulations given in each comparison condition. Given significant findings in the ANOVA, post hoc comparisons of every condition will be conducted at a new alpha of .01 (corrected for 6 comparisons (MS Vs NI, MS Vs NIT, MS Vs UV, UV Vs NI, UV Vs NIT, NI Vs NIT)). Based on the pilot data in Figure 3, we would expect to see activation most pronounced over mid-frontal distributions, covering F1 and FC1 electrodes and therefore these electrodes are selected as the electrodes of interest.

Interpretations for hypothesis 2 can be found in the design table (Appendix A).

*2.5 Power Analysis*

2.5.1 Hypothesis 1 (Positive Control)

Effect sizes are determined by research from Hansford et al. (2023a) using the subjective illusory experience questionnaire and comparing MS, UV, and incongruent finger-based resizing illusions to control conditions with no illusory resizing, using the same finger stretching illusions and the same equipment (n = 48), which show an effect size of η 2 = .33 (converted to a Cohen’s f = .70). Additional effect size information comes from a visual capture study (n = 80) using a subjective embodiment questionnaire and visual and tactile manipulations to a mannequin body (Carey et al., 2019), showing an effect size of r = .64 (converted to a Cohen’s f = .83) when comparing embodiment scores from the questionnaire against control scores. An effect size of f = .70 was used for hypothesis 1 to adhere to the lower end of previous effect sizes.

A priori power analysis using G\*Power for the smallest effect size of interest (f = .70) shows that for a repeated measures, within factors one way ANOVA, with an effect size (f) of 0.70, alpha of 0.05, power at 90% and 1 group with four measurements, 6 participants are needed.

2.5.2 Hypothesis 2

This is the first study to investigate illusory finger stretching using SSEPs, so appropriate effect size estimates are not available. We therefore conducted power calculations based on a smallest effect size of interest, in line with the recommendation of Lakens (2014). Here, we have chosen an effect size of d = 0.5 (a medium effect, see Cohen, 1988), since this is the smallest effect size we are interested in detecting, which we have converted to a Cohen’s f of 0.25 for power analyses.

A priori power analysis using G\*Power shows that for a repeated measures, within factors one way ANOVA, with an effect size (f) of 0.25, alpha of 0.05, power at 90%, and 1 group with four measurements, a total sample size of 30 participants is needed.

A Design planner (Table A1) encompassing research questions, hypotheses, sampling and analysis plans and their resulting interpretations can be seen in appendix A.

**3. Pilot Data**

Previous literature states that the ideal vibration frequency to use to elicit somatosensory steady state evoked potentials (SSSEPs) is approximately 26Hz (Muller et al., 2001; Breitweiser et al., 2016; Pokorny et al., 2016; Snyder, 1992). Due to resizing illusions often manipulating the index finger, and previous studies using the index finger supporting around 26Hz as an optimal frequency (Muller et al., 2001; Breitweiser et al., 2016; Pokorny et al., 2016), it was hypothesised that 26Hz would elicit a dependable SSSEP. Therefore, we ran a pilot study to check that our setup and equipment can reliably elicit and record a SSSEP at 26Hz, using the resizing illusion and EEG.

Pilot data were collected for 3 healthy participants. Participants underwent the same experimental protocol as mentioned in the “Experimental Procedure” section, minus the subjective illusory experience questionnaire. A Fourier transform was calculated for each waveform at each electrode for all conditions, and then averaged across repetition to obtain individual results. These were then averaged across all 3 participants to give the result seen in Figure 3.

A screenshot of a computer

Description automatically generated As can be seen, there is a clear SSSEP response at 26Hz, which is strongest around electrodes F1 and FC1. Previous research using vibrotactile stimulation at 21Hz have also found the scalp topography of the activation to be most pronounced over mid-frontal distributions (Porcu et al., 2014; Timora & Budd, 2018), in line with the scalp topography seen here. Given these finding of a distinct 26Hz signal and mid-frontal scalp location, it appears appropriate for 26Hz to be used as the vibration frequency in the proposed study.

*Figure 3*. Averaged Pilot Data showing peak frequency at 26Hz, centred between electrodes F1 and FC1. The spectrum is derived from electrode FC1. Saturation bar represents signal to noise ratio (SNR).

Chart

Description automatically generated with medium confidence Pilot data were also collected using the vibrotactile stimulator at 26Hz to make sure that the illusory experience is not affected by the addition of vibrotactile input. Pilot data were collected from 4 additional healthy participants, who underwent the same experimental protocol as mentioned in the “Experimental Procedure” section, but without EEG caps fitted. Illusory experience was calculated using the median of both illusion scores for each participant minus their median control scores, as per the preprocessing steps regarding the control index, and then the data were averaged over participants to give the results seen in Figure 4. As can be seen, there is a greater subjective experience of the resizing illusion, indexed by participant’s illusion score, in both experimental conditions (UV average = 64.25; MS average = 67.88) compared to both control conditions (NI average = 32.38; NIT average = 24.13). Scores below 50 are indicative of disagreement of experience of the illusion, whilst a score of 50 is a neutral option regarding the illusion experience, and scores above 50 are indicative of agreement of experiencing the illusion. This therefore shows that the experience of illusory resizing is maintained when vibrotactile stimulation is added to the procedure and can therefore be used in the proposed study to elicit SSEPs without affecting the subjective illusory experience of the resizing illusion.

*Figure 4*. Averaged Illusion score for each condition. Error bars represent standard errors. NI represents the non-Illusion condition, NIT refers to the non-illusion tactile condition, UV refers to the unimodal-visual condition, and MS refers to the multisensory condition.

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**Appendix A**

Table A1: Design Planner

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Question** | **Hypothesis** | **Sampling plan (e.g., power analysis)** | **Analysis plan** | **Interpretation given different outcomes** | **Theory that could be proved wrong given outcomes** |
| Does the finding of greater subjective illusory experience in multisensory compared to non-illusion conditions replicate in this study? | (1 – Positive Control) There will be a greater illusory experience, measured via a subjective illusory experience questionnaire, in the MS condition compared to the NI and NIT conditions. | A priori power analysis using G\*Power shows that for a repeated measures, within factors ANOVA, with an effect size (f) of 0.73, alpha of 0.05, power at 90% and 1 group with four measurements, 5 participants are needed. | An ANOVA will be run to compare median scores from each condition. Given significant findings, post-hoc tests will be run, with Bonferroni correction for 4 comparisons at an initial alpha of 0.05 (adjusted alpha = .0125). | If Hypothesis 1is supported: Indicates that the augmented reality manipulations are inducing effective illusions, and shows success of positive control, giving weight to the subsequent EEG findings.  If Hypothesis 1is unsupported (No significant difference comparing MS to both NI and NIT): Indicates that the augmented reality manipulations are not inducing effective illusions, and therefore the findings regarding hypotheses 2 will be called into question.  (No significant difference comparing MS to NI): Indicates that tactile input is needed for an effective non illusion condition, calling EEG analyses with NI condition into question.  (No significant difference comparing MS to NIT): Indicates that tactile input removes effect of NIT condition, calling EEG analyses with NIT condition into question. | The theory that adding vibrotactile stimulation will not influence the subjective illusion experience of resizing illusions would be proved wrong within this sample if hypothesis is unsupported. |
| Are there significant changes in the somatosensory response when comparing different conditions healthy participants? | (2) There will be a significant difference in SSEP response across the electrodes of interest (F1 & FC1) when comparing across all conditions | A priori power analysis using G\*Power shows that for a repeated measures, within factors one way ANOVA, with an effect size of f = .25, alpha of 0.05, power at 90%, and 1 group with four measurements, a total sample size of 30 participants is needed. | A repeated measures one way ANOVA will be run comparing all experimental conditions. The dependant variable will be SSSEP amplitude in µV. | If Hypothesis 2 is supported: Indicates that there are significant differences in SSEP response when comparing across all conditions in healthy participants.  If Hypothesis 2 is unsupported: Indicates that there is no evidence of a significant difference in SSEP response when comparing across all conditions in healthy participants. This will result in hypotheses 2a – 2c being unsupported. | The theory regarding cortical changes in somatosensory representation during illusory finger stretching would be proved wrong if hypothesis 2 is unsupported. |
| Are there significant changes in the somatosensory response when comparing the multisensory visuotactile to the non-illusion condition in healthy participants? | (2a) There will be a significant difference in SSEP response across the electrodes of interest (F1 & FC1) when comparing the MS illusory resizing condition to the NI condition. | A priori power analysis using G\*Power shows that for a repeated measures, within factors one way ANOVA, with an effect size of f = .25, alpha of 0.05, power at 90%, and 1 group with four measurements, a total sample size of 30 participants is needed. | A post hoc comparison will be run after the repeated measures one way ANOVA to compare the MS condition to the NI condition. The dependant variable will be SSSEP amplitude in µV. | If Hypothesis 2a is supported: Indicates that there are significant differences between MS and the NI condition in healthy participants.  If Hypothesis 2a is unsupported: Indicates that there is no evidence of a difference between MS and the NI condition in a healthy population. | The theory regarding cortical changes in somatosensory representation during multisensory illusory finger stretching would be proved wrong if hypothesis 2a is unsupported. |
| Are there significant changes in the somatosensory cortex when comparing the unimodal visual condition to the non-illusion condition in healthy participants? | (2b) There will be a significant difference in SSEP response across the electrodes of interest (F1 & FC1) when comparing the UV illusory resizing condition to the NI condition*.* | A priori power analysis using G\*Power shows that for repeated measures, within factors one way ANOVA, with an effect size of f = .25, alpha of 0.05, power at 90%, and 1 group with four measurements, a total sample size of 30 participants is needed. | A post hoc comparison will be run after the repeated measures one way ANOVA to compare the UV condition to the NI condition. The dependant variable will be SSSEP amplitude in µV. | If Hypothesis 2b is supported: Indicates that there are significant differences between UV and the NI condition in healthy participants.  If Hypothesis 2b is unsupported: Indicates that there is no evidence of a difference between UV and the NI condition in a healthy population. | The theory regarding cortical changes in somatosensory representation during unimodal visual illusory finger stretching would be proved wrong if hypothesis 2b is unsupported. |
| Are there significant changes in the somatosensory cortex when comparing the non-illusion tactile condition to the non-illusion condition in healthy participants? | (2c) There will no significant difference in SSEP response across the electrodes of interest (F1 & FC1) when comparing the NIT condition to the NI condition*.* | A priori power analysis using G\*Power shows that for repeated measures, within factors one way ANOVA, with an effect size of f = .25, alpha of 0.05, power at 90%, and 1 group with four measurements, a total sample size of 30 participants is needed. | A post hoc comparison will be run after the repeated measures one way ANOVA to compare the NIT condition to the NI condition. The dependant variable will be SSSEP amplitude in µV. | If Hypothesis 2c is supported: Indicates that there are no significant differences between NIT and NI conditions in healthy participants.  If Hypothesis 2c is unsupported: Indicates that there is evidence of a difference between NIT and NI conditions in a healthy population. | The theory that tactile input alone will not give significant differences in cortical changes in somatosensory representation during non-illusion conditions would be proved wrong if hypothesis 2c is unsupported. |

**Appendix B:**

A screenshot of a computer

Description automatically generatedPilot data regarding the experience of the illusion for healthy participants undergoing synchronous and asynchronous illusory resizing of the index finger can be seen in figure B1. 9 participants had either synchronous or asynchronous multimodal manipulations delivered first in a random order, and were then given the other condition, after which all participants were given an illusion scale. Findings showed that across all participants, no significant difference in illusion experience between the synchronous and asynchronous conditions, t(8) = 1.877, p = 0.097, however as can be seen in figure B1, despite the small sample size, illusion strength was seen to be greater in the synchronous condition compared to the asynchronous condition.

Figure B1. Pilot data from Healthy Participants Undergoing Synchronous and Asynchronous Illusory Finger Resizing.