An Investigation into the Effect of the Manipulation of Stimuli Elicitation Synchronization on the Brain's Connection and Sense of Ownership with a Prosthetic

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Disruption in sensory feedback can impair the brain's ability to predict temporal and spatial congruence, often resulting in the perception of false stimuli. The sense of body ownership relies on the brain's ability to integrate visual and tactile information across time through top-down processing and multisensory integration, allowing it to fill informational gaps. This study investigates how the synchronization of visual and tactile stimuli affects perceived ownership in the Rubber Hand Illusion (RHI) among neurotypical adolescents. Thirty right-handed students were randomly assigned to one of three conditions with varying levels of synchrony, and ownership was rated on a three-item Likert scale assessing responses to stylus, brush, and ice stimulation. Results showed that synchronized stimuli significantly enhanced the sense of ownership over the rubber hand, supporting theories of neuroplasticity and Bayesian sensory integration. By visualizing and sensing the same stimulus, participants perceived the rubber hand as their own hand. These findings provide baseline evidence on body ownership and temporal synchrony, suggesting approaches for future research that incorporate physiological measures.

Keywords: Rubber Hand Illusion, Neuroplasticity, Sensory Perception, Cognitive Integration, Predictive Coding, Multisensory Integration, Body Ownership, Temporal Synchrony

Introduction

Through traumatic injury, amputation, or congenital defects, over 35 million people worldwide (about twice the population of New York) use artificial limbs[1]. These prosthetics must be mentally and physically integrated into the body, but even a physically perfect device may not feel right. They become a part of their real body, pushing individuals to adjust to them despite the discomfort. Successful embodiment requires the development of a perceptual link between a biological and artificial limb. A functioning prosthetic uses the brain's generated electrical signals which travel through nerves and are picked up by the prosthesis' sensors. The motor cortex (located in the frontal lobe) sends signals to initiate movement and control various parts of the body, and the somatosensory cortex processes sensory information as described by Figure 1. These inputs run in the dorsal columnmedial lemniscus pathway, synapsing in the thalamus before being projected to the primary somatosensory cortex (postcentral gyrus), where proprioceptive and tactile data are integrated[2]. The alignment of visual, tactile, and proprioceptive cues gives rise to the sense of body ownership, emerging from the integration of information across several sensory systems. When these factors do not align, the brain may produce false sensations or misattribute body parts. Experiments such as the Rubber Hand Illusion (RHI) produce evidence pointing to how temporal alignment can shape ownership[3]. This study explores this very phenomena, assessing the brain's ability to be readily adaptive by using prior knowledge and experiences to predict incoming sensory information by the interpretation of sensory data through the use of the Rubber Hand Illusion.

Proprioception allows the brain to understand body movement through receptors in muscles and joints, sending signals which travel through fibers through the dorsal column pathways to the thalamus and somatosensory cortex. These signals are then integrated with visual and tactile inputs an individual experiences, maintaining a coherent sense of the body's positions. In amputees, the disturbance of these signals triggers cortical reorganization in the somatosensory cortex, often resulting in altered proprioceptive feedback or phantom sensation. One of the most relevant theories based on the concept of ownership of a limb is the top-down processing model, describing how the brain makes use of already established information to construct a model reflecting the whole perceptual experience. This can be supported by the Bayesian Brain Theory which explains how the nervous system integrates information from different sensory outputs to fill in information and understand our environment. The theory supports the brain's ability to compare expected sensory input with incoming data and update its body schema based

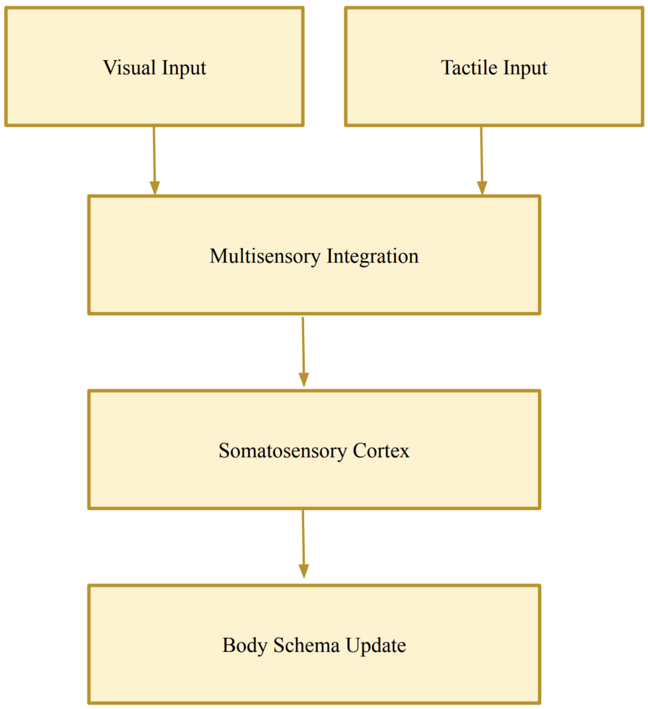

Fig. 1 Sensory integration pathway in the brain during prosthetic feedback processing.

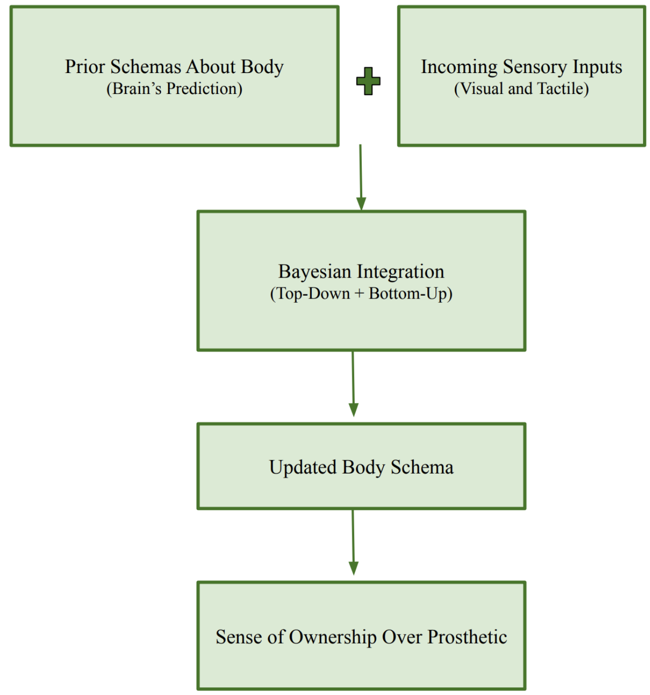

Fig. 2 Bayesian integration process in the development of prosthetic limb ownership.

on prior information. Figure 2 demonstrates how Bayesian integration adjusts its internal model to minimize prediction error, contributing to the sense of body ownership. The Bayesian Brain Theory elucidates this notion of the nervous system being able to operate in situations of uncertainty, such as being able to create false precepts in the absence of a familiar stimulus[4]. When visual and tactile stimuli are experienced in close temporal alignment, the brain can interpret the events as originating from the same source. Coherence, however, deteriorates in response to delayed or disconsonant stimuli, demonstrating the brain's adaptive nature in relation to body representation.

Previous research on the Rubber Hand Illusion has demonstrated that ownership perception is strongly dependent on the temporal and spatial congruence of visuo-tactile signals. Asynchronous presentation of these signals weakens the illusion, highlighting the brain's sensitivity to timing differences in multisensory integration. Though most studies have focused data on adult populations; the narrowed age group leaves less information about how the mechanism operates in adolescents- a group characterized by high neuroplasticity- and how body representation continues to adapt in developmental stages parallel to experience. Therefore, this experiment aims to evaluate how manipulation of synchronization levels influence the perceived sense of ownership in the RHI. By supporting the theory, synchrony was tested, and a connection was attempted to be established between the brain and rubber hand. By seeing a stimulus inflicted upon the rubber hand but feeling it on the real hand, the brain attempts to integrate this visual and tactile information, leading to the perception that the rubber hand is part of their body. This will be assessed by manipulating the synchronization by which the stimuli will be elicited. The synchronization of stimuli will vary by experiencing different timing conditions: synchronous (simultaneous stimuli), asynchronous 0.5 second delay, and asynchronous 3.0 second delay. This will ultimately be evaluated by a structured questionnaire to measure perceived ownership.

Variables Independent variable: Temporal synchrony - time (seconds) between elicitation of visual and tactile stimulus on biological vs. rubber hand (0s, 0.5s, 3s)

Dependent variable: level of ownership felt towards the rubber hand (rated 1-7 on Likert Scale)

Experimental Hypothesis: If the placement of the stimuli is synchronized (inflicted at the same time 0s delay), it will produce a stronger sense of ownership between the prosthetic and biological limb, describing how the brain's capacity for neuroplasticity and multisensory integration, in which temporal alignment enhances information intake.

Null hypothesis: The synchronization of the stimuli will have no effect on the sense of ownership over the rubber hand.

Similar to the traditional design of the Rubber Hand Illusion, this experiment specifically utilizes the manipulation of synchronization to assess how correlated multisensory signals shape the feeling of ownership[5]. Through the time of the onset of the stimulus, the position of it seen and felt, illusory distortions can be experienced with the change of shape, size, and possibly color of the rubber hand to match a person's true limb[6]. Based on the extent that the brain adjusts itself to the visual and tactile stimulation, the ventral premotor cortex anatomically connects with higher-order somatosensory areas post the receival of proprioceptive input. This process aligns with multi-sensory perception theory, which explains how the brain can integrate information from different sensory outputs (touch, sight, hearing, taste, smell) to fill in information and understand their environment[7]. This theory is consistent with the contribution of the ventral premotor cortex to self-attribution of body parts when being able to recognize and differentiate between limbs[8]. These mechanisms demonstrate the neural processes underlying body ownership and highlight the capacity of perceptual systems to adapt altered sensory environments. The results observed in this study may establish a foundation for implications that could benefit research and experimentation on prosthetic limbs, informing technological advancements that enhance embodiment and user experience. By applying the Rubber Hand Illusion concept to a group of neurotypical adolescents, this study investigates how multisensory integration and temporal synchrony affect perceived ownership.

Methods

This experiment was conducted with thirty right-handed 10th-grade students recruited through opportunity sampling from chemistry classes. This restricted the sample to neurotypical adolescents with similar cognitive abilities and age. Participants were randomly assigned into the three groups (synchronous, 0.5 second delay, or 3.0 second delay) to reduce expectancy bias through a self-programmed computer-based timer, which also standardized stimulus synchronization. To guarantee uniformity across all trials, the timer was programmed to indicate precise delay intervals between visual and tactile events. Although the tactile stimuli were manually applied by a researcher, the program's automated system reduced variability. This system offered dependable temporal control within the setup's constraints, despite achieving semi-automation rather than full.

The experiment follows an independent-groups design, ensuring the prevention of cross condition influence- responses from one condition would not influence another. Gender distribution was not controlled and is acknowledged as a limitation due to possible perceptual variation. The illusion was evaluated based on three different stimuli (tap, brush, temperature), all administered to the left hand of every individual. The full procedure was rehearsed prior to its conduction to ensure uniform timing, positioning, and application pressure throughout the experiment.

In order to keep the results as organic as possible, the designed ownership questionnaire avoids leading questions or suggestive wording and is answered from 1-7 based on the Likert scale for each item. The applied pressure of the stimuli was kept the same across participants, as variability may influence the strength of the illusion.

Although the results of the experiment will differ person to person and may be affected by the expectancy bias from participants wanting the experiment to work, the procedure is designed to minimize confounding variables. Individual differences including different levels of susceptibility to the illusion based on prior experience, psychological and cognitive differences will also be present, along with the degree to which the participants will give attention to the rubber hand. To further reduce expectancy bias, participants were provided with neutral instructions that emphasized sensory observation, without referencing the RHI phenomena or ownership.

All participants are given identical instructions and assent forms (Appendix iii, ii). The procedure of the experiment is clearly explained to eliminate deception and minimize confusion, and participants will be thoroughly debriefed when the study has been concluded (Appendix iv). The illusion was induced with three differing stimuli to generalize findings across sensory modalities and ensure effects are not specific to a type of catalyst. Using different stimuli strengthens the theory used for the experiment, allowing the determination of the brain's processes, specifically of the integration of sensory information. This can allow the exploration of specific mechanisms in the illusion. Moreover, the variability and reliability of the experiment can be increased by the different materials to avoid confounding variables by ensuring that the effects observed by the illusion are from the intended manipulation rather than an inadvertent factor. During the debriefing stage, participants' reports of proprioceptive drift- their perceived hand position in relation to the rubber hand- were qualitatively observed. Despite the lack of quantitative drift measurements, this observation subsidizes ownership responses obtained from the questionnaire.

The participant's left hand will be placed in a cardboard box so it is not visible to them, and their right hand will be on a table so that it is parallel to a realistic (as possible) rubber hand. As shown in Figure 3, a blank cloth will cover the area between the prosthetic and the left shoulder to create a visual connection. Based on the assigned condition, a researcher will apply tactile stimuli (brush, tap, ice) to both the rubber hand and their real hand. Synchronous: simultaneous stimulus on both hands; asynchronous 0.5s: stimuli on biological hand followed by rubber hand after 0.5s; asynchronous 3.0s: stimuli on biological hand followed by rubber hand after 3.0s. All stimuli will be applied to corresponding locations on the participant's real and rubber hands on the radial region of the dorsum (between the second and third metacarpal bones) to maintain spatial congruence. This will go on for a duration of 15 seconds with two-minute intervals between each stimulus, followed by the seven statements that will be read aloud for them to respond to from 1-7 based on

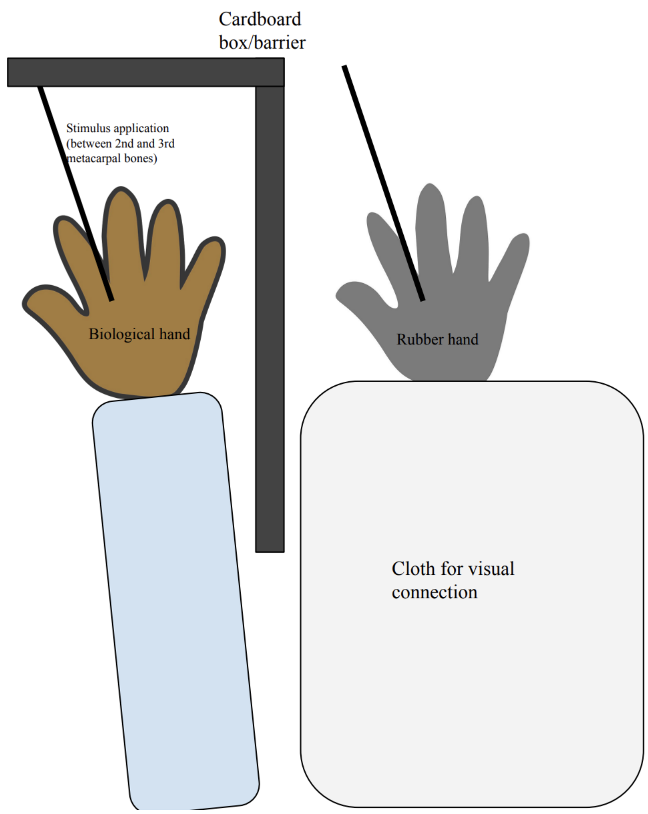

Fig. 3 Summary of experimental set up.

how much it applies to their experience (strongly disagree → strongly agree) (Appendix v- full procedure):

Table 1 Statements list, including the distinction between what is considered in the results (not control) and what is not considered (control)

Control/Not control	**Statement (Stylus tap)**	**Statement (Brush)**	**Statement (Ice)**
Not control	I felt as if the prosthetic was my hand.	I felt as if the prosthetic was my hand.	I felt as if the prosthetic was my hand.
Not control	It seemed as if the sensation I felt was caused by the sensation I saw on the prosthetic hand.	It seemed as if the brush sensation I felt was caused by the sensation I saw on the prosthetic hand.	It seemed as if the sensation I felt was caused by the sensation I saw on the prosthetic hand.
Not control	It seemed like I was directly looking at my own hand rather than a prosthetic.	It seemed like I was directly looking at my own hand rather than a prosthetic.	It seemed like I was directly looking at my own hand rather than a prosthetic.
Not control	It seemed like the prosthetic hand was a part of my body.	It seemed like the prosthetic hand was a part of my body.	It seemed like the prosthetic hand was a part of my body.
Control (not considered for data)	It felt as if my right hand was drifting towards the prosthetic hand.	It felt as if my right hand was drifting towards the prosthetic hand.	It felt as if my right hand was drifting towards the prosthetic hand.
Control (not considered for data)	It appeared as if the prosthetic limb was drifting towards my right hand.	It appeared as if the prosthetic limb was drifting towards my right hand.	It appeared as if the prosthetic limb was drifting towards my right hand.
Control (not considered for data)	The prosthetic hand started to change shape, color, and appearance so that it started to resemble my right hand (visually)	The prosthetic hand started to change shape, color, and appearance so that it started to resemble my right hand (visually)	The prosthetic hand started to change shape, color, and appearance so that it started to resemble my right hand (visually)

Analysis & Results

Out of the seven questionnaire statements, the first four were considered for our data to assess illusion strength, while the remaining three served as control questions as distractions to detect bias. These statements measured how strongly the prosthetic hand influenced the participant's perception, which were ultimately averaged out per group to analyze the most successful group. The closer the value is to 7, the stronger the ownership towards the prosthetic hand. Internal consistency of the three-item ownership measure was excellent (Cronbach's $\alpha = 0.95$; item range = 0.89 – 0.94), indicating a strong reliability across stimulus type. Groups were labeled as Sync (synchronous), Async5 (0.5s delay), Async3 (3.0s delay).

The mean scores between Sync (5.45), Async5 (3.23), and Async3 (2.32) were distinctly different, suggesting a correlation between stimulus timing and perceived ownership. Group means ($\pm SD$, 95 % CI) were: synchronous 5.45 ± 1.40 [4.45 – 6.45]; Async5 3.23 ± 1.44 [2.20 – 4.26]; and Async3 2.32 ± 0.95[1.64 – 3.00] (Appendix xi)[9]. Based on the data, participants in the Sync condition felt the greatest connection with the rubber hand, followed by Async5, then lastly Async3. This proves that shorter temporal delays between visual and tactile stimulus contribute to

Table 2 Descriptive Statistics of Data (seconds) (raw data: Appendix vi, vii)

	Synchronous	Asynchronous (0.5 sec.)	Asynchronous (3.0 sec.)
Mean	5.45	3.23	2.32
Range	4.34	4.5	2.42
Standard Deviation	1.4	1.44	0.95

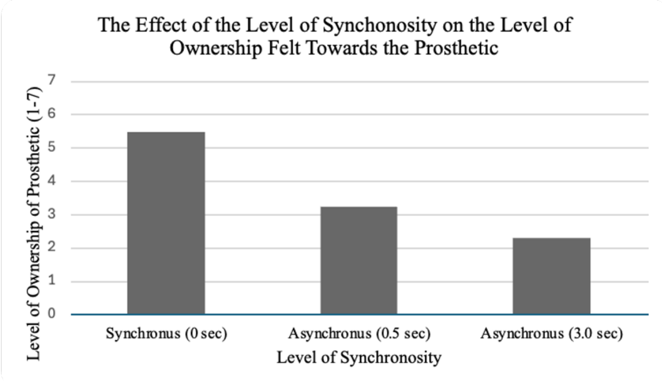

Fig. 4 Mean level of ownership of the rubber hand felt by participants for three conditions

greater ownership perception. Additionally, although the Sync and Async5 groups had relatively similar standard deviations (1.40, 1.44 respectively), Async3 had a much lower standard deviation (0.95) which may imply that the data is comparatively less spread out. Because all three standard deviations were low, this suggests that the data can be considered reliable when interpreting it, although further inferential statistics were considered for validation of the results.

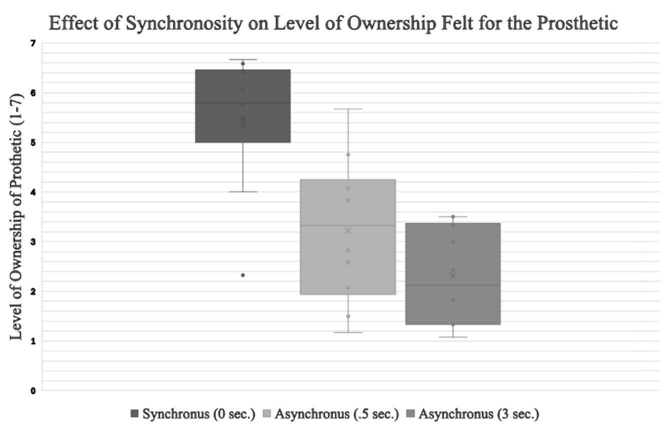

Fig. 5 Data distribution, potential outliers, and mean level of ownership of the rubber hand felt for three conditions

Prior to the conduction of inferential analysis, data was evaluated for assumptions through Shapiro-Wilk tests. This test confirmed that ownership ratings were normally distributed for each condition, with no strong departures from normality in the Async5 group (W = .97, p= .931) or Async3 (W = .88, p =. 139). Though the synchronous group showed a mild deviation (W = .82, p = .030), conduction of Levene's test indicated homogeneity of variance across groups (F(2, 27) = 0.69, p = .51) (Appendix x). Given that the ANOVA is robust to mild normality violations, the analysis proceeded. The results of a conducted One-way ANOVA test showed that the p-value of the data was p = 2.37e-05, $p < 0.05$; F (2,27) = 16.21,$p < 0.001$, with a large effect size (partial$\eta^2 = .55$ [.24, .68], $\omega^2 = .50$, Cohen's $f = 1.01$ (Appendix xi)[10]. This shows that the data is statistically significant, meaning the null hypothesis can be rejected. A Tukey HSD Post-Hoc Testing was then conducted to reduce the risk of false positives and determine which groups differ, revealing significant differences between both Sync and Async5 (1.54e–03), as well as Sync and Async3 (1.01e–3), but not between Async5 and Async (Appendix ix). These findings support that the hypothesis can be accepted, and the null hypothesis can simultaneously be rejected, indicating that placing the stimuli synchronously on the biological and rubber hands constructs the strongest sense of ownership. Thus, it can be said that synchronization significantly strengthens the perception of ownership of an artificial limb.

Conclusion and Methods

Sustaining sensory deafferentation can disrupt the brain's ability to make predictions based on temporal and spatial incongruity. The reorganization of the sensory cortex which processes and makes sense of sensory information can compensate for missing information and activate areas of the brain crucial for stimulus detection. For the purpose of reducing uncertainty correlated to deafferentation, the sensory cortex's hyperactivity will result in the perception of false information (e.g. feeling a sensation that is not actually on your own hand). This experiment and its results are consistent with the the top-down processing model and Bayesian integration by describing the brain's capacity to use existing knowledge and multisensory information to fill in perceptual gaps. The current study examined perceptual aspects of visuo-tactile synchrony in the RHI, without testing sensorimotor feedback loops. Real prosthetic embodiment involved bidirectional integration of motor commands, and sensory inputs, which our design could not model[11]. The Rubber Hand Illusion demonstrates how the brain integrates visual and sensory perception into a cohesive representation when experienced simultaneously, dropping prediction error and enabling ownership of a rubber hand as part of one's own body.

The highest mean (scale of 1-7) observed in the synchronous group (5.45) displays the link that can be developed when visualizing and sensing a stimulus at the same time. As the synchronization of the catalyst increases, the participant's responses to the questionnaire approach 7, reflecting stronger ownership perception. The group with the most time between the stimuli being presented on the rubber and biological hands had the least average in the questionnaire of only 2.32, less than half of that of the synchronous condition. These findings can be explained through the top-down processing model akin to the Bayesian Brain Theory, supporting that the alignment of the sensory inputs' coordination harmonized with the brain's expectation for temporal congruence can strengthen perceptual binding[12]. The

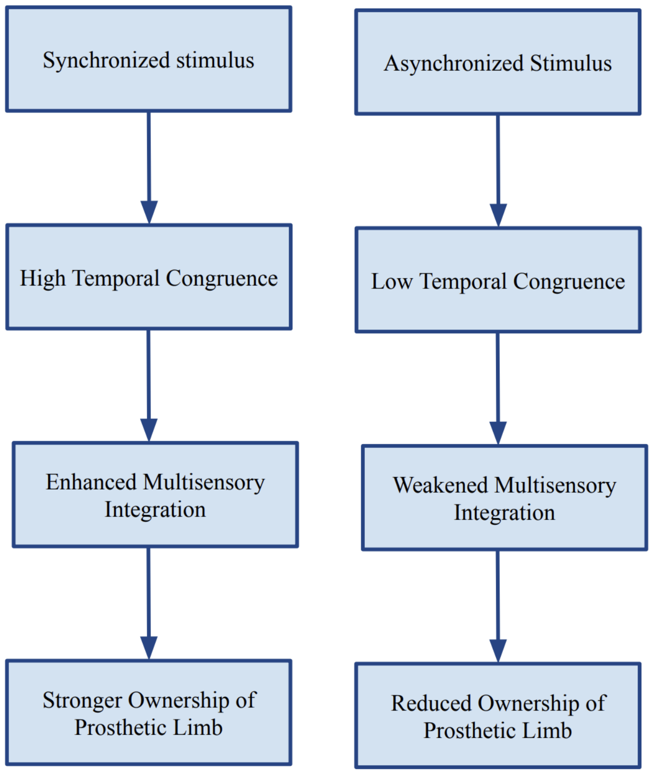

Fig. 6 A general schematic of synchronization on Multisensory Integration and artificial limb ownership.

visual and tactile inputs allowed for the integration of the rubber hand into their established body schema, proposing the brain's adaptation of its predictions based on preexisting ideas and new stimuli. As illustrated in Figure 4, synchronized stimuli produced stronger multisensory integration, resulting in an increased ownership perception. This supports the hypothesis that synchronized conditions induce greater ownership towards the rubber hand as the brain adjusts its standards to incorporate it into its internal model, ultimately creating a robust perceptual shift. The difference in time between the sensations in both asynchronous groups establish less consistent sensory information, weakening integration and embodiment. This study's independent measures allow the elimination of order effects since each participant was assigned to a single condition. Because of this, participants could not infer the hypothesis, reducing the possibility of demand characteristics or a placebo effect. The mix of gender and backgrounds of participants broadens the generalizability of the study's and improves population validity. Another strength of the design is the consistent procedure (Appendix v) and standardized instructions to all participants. No participants were told anything different to reduce variability in the interpretation of the experiment, increasing internal validity. One key strength of the design was the use of three different stimuli which enhanced the reliability of the data by making certain that the illusions' observed effects resulted from the deliberate manipulation, rather than unintended variables. Lastly, the inclusion of three control questions in the questionnaire not considered for the data minimized response bias by discouraging participants from guessing the purpose of the experiment and adjusting their answers to align with the optimal response. Although the findings reflected high internal consistency, generalizability can be limited by a number of factors. The opportunity sample of tenth-grade students diminishes its external validity, as age, developmental stage, and cultural background can influence perceptual integration. Adolescent neuroplasticity may introduce variability in the perception of ownership. The familiar school setting where the experiment took place may deem ecological validity low, since it does not reflect clinical or everyday sensory environments. Furthermore, given known gender-related differences in multisensory integration, the skewed gender distribution among the subjects possibly impacted perceptual responses. Population validity and possibility for the results to be extrapolated to a larger population may be attained with a more representative and gender-balanced sample. The results are based on perceptual mechanisms rather than true clinical embodiment, as the study involved healthy individuals using a simulated. They may not be the same for people who have limb loss and have changed sensory feedback. Additionally, because the experiment took place in a single session, no conclusions can be made concerning adaptation or neuroplasticity. In future studies, multi-session protocols should be used in order to examine the effects of repeated exposure on the strength of ownership and integration at the neural level. Visual mismatches, for example, the participant's skin tone differing from the rubber hand's, may possibly lead to a different perception, aligning with prior evidence that visual congruence improves embodiment. Moreover, the measure of ownership exclusively utilized scores in self-ratings, which are subject to expectancy or response bias. Proprioceptive drift and subjective ownership are known to sometimes dissociate, and including physiological measures such as skin conductance, an EEG, or EMG could provide more insight into the neural processes underlying the illusion[13]. Although drift measurements have technical limitations, combining them with subjective ratings and physiological measures can provide a more comprehensive assessment of body ownership[14]. Additionally, the extent of a participant's attention towards the experiment is a limitation, because a person concentrating on sensory experience more may feel a greater ownership towards the prosthetic than those who were less attentive. This variability may have influenced responses to the questionnaire, potentially reducing accuracy. Moreover, although stimulus synchrony was controlled by a semi-automated computer program, subtle inconsistencies in timing could still influence the results. As a modification, future experimentation could implement a full mechanical system for maximum accuracy in removing potential confounding variables. Also, the study's limited delay conditions do not capture the whole temporal binding window for visuospatial integration fully. Adding more specific delay intervals and adding negative controls like spatial mismatches, visual-only stimuli, or longer asynchronous delays, can allow for clearer distinguishment of more temporal and synchrony-specific effects from more general multisensory stimulation. Ultimately, optimizing synchronization between sensory inputs advances more robust multisensory integration and coherence for the body-schema, illustrating the way in which timing and perception in combination defines the brain's sense of embodiment. Therefore, while the current work provides insights into temporal synchrony and body representation, the inferences should be limited to models of ownership at the perceptual level.

Discussions

Modern day technology offers amputees a wide variety of choices in function and purpose. Body powered prostheses are controlled by the body, and these can be especially useful for a hand amputation to restore the ability to pick up objects and even engage in manual labor[15]. Second, a motor-powered prosthesis has buttons that controls movements, such as one to articulate finger movements to pick up an object or point to something. Lastly, the recent development of myoelectric powered prosthetics, the most advanced of the three, allows controlling prosthetic limbs by electric signals sent to the device through electrodes placed on the skin[16]. The degree of sensory feedback these systems offer varies, with myoelectric most closely resembling a biological limb in terms of its timing and responsiveness. The synchrony principle tested in this experiment, where simultaneous visual and tactile cues improved ownership perception, is mirrored in this temporal precision.

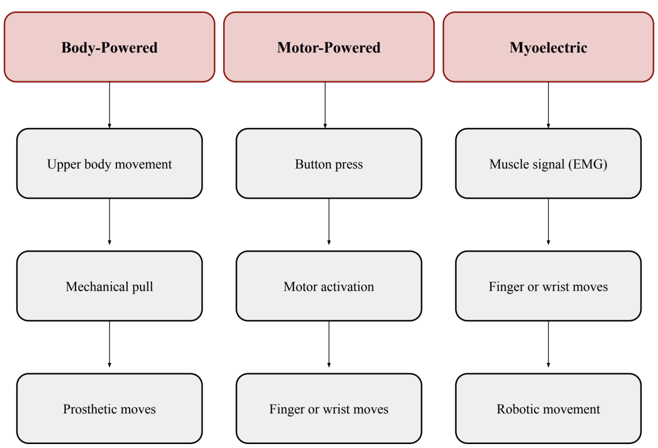

Fig. 7 A brief comparison of upper-limb prostheses based on their activation mechanisms.

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Effect size

Appendix

Appendix i: Parental Consent Form

Parent/Guardian Consent Form

* Indicates required question

1. Email *

The Rubber Hand Experiment

This study analyzes neuroplasticity and how our brain can accommodate to new stimuli to "fill in the blanks". It uses the idea of proprioception and kinesthesia, the ability for the body to sense its own parts, to study the **Bayesian Brain Theory**. According to this theory, the brain uses prior knowledge and experiences to predict incoming sensory information by interpreting sensory data. This allows the brain to be rapidly adaptive, allowing it to update its model when it predicts an incongruity with predicted and actual sensory output. This experiment will use different stimulis to explore how to brain can enable sensory feedback to take ownership of prosthetic limbs.

Additional Considerations

In order to participate in this research study, it is necessary that you give your informed consent. By signing this informed consent statement you are indicating that you understand the nature of the research study and your role in that research and that you agree to participate in the research. Please consider the following points before signing:

I understand that I am participating in psychological research;

I understand that my identity will not be linked with my data, and that all information I provide will remain confidential;

I understand that I will be provided with an explanation of the research in which I participated.

I understand that certain facts about the study might be withheld from me, and the researchers might not, initially, tell me the true or full purpose of the study. However, the complete facts and true purpose of the study will be revealed to me at the completion of the study session.

I understand that participation in research is not required, is voluntary, and that, after any individual research project has begun, I may refuse to participate further without penalty.

2. Do you consent to your child's participation in our study? *

   Mark only one oval.

   - I Consent
   - I Do Not Consent

3. Name of student you are giving consent for: *

4. Your Name: *

Student Information

Please fill in the information based on the **participant (student)**.

5. Please enter your birth year: *

6. Please select your grade: *

   Mark only one oval.

   - 9th
   - 10th
   - 11th
   - 12th

7. What is your most dominant hand? *

   Mark only one oval.

   - Left
   - Right

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Google Forms

Appendix ii: Assent Form

This study analyzes neuroplasticity and how our brain can accommodate new stimuli to "fill in the blanks". It uses the idea of proprioception and kinesthesia, the ability for the body to sense its own parts, to study the **Bayesian Brain Theory**. According to this theory, the brain uses prior knowledge and experiences to predict incoming sensory information by interpreting sensory data. This allows the brain to be rapidly adaptive, allowing it to update its model when it predicts an incongruity with predicted and actual sensory output. This experiment will use different stimuli to explore how the brain can enable sensory feedback to take ownership of prosthetic limbs. You may opt out of this study at any time and withdraw your results if you choose to do so.

Name:

#:

Select one:
I consent x I do not consent x

Appendix iii: Standardized Instructions

Hi! We are psychology researchers conducting an experiment for our internal assessment. Thank you for participating.

Please place your left hand in the hole of the cardboard box. During this experiment, you will feel the following three things and nothing else; a pencil tap, a brush, and ice. Please place your right hand on the desk so that your middle finger aligns with the blue tape on the desk. Now, we will be putting a white cloth over your shoulder. You will feel and see the three stimuli one at a time, and after a certain amount of time it will stop. After each one, we will say a series of statements to which you will respond on a scale of 1-7 based on how much that statement applies to you- 1 being very true of me to 7 being very true of me. In other words, based on how much you agree with that statement. Please keep looking at the rubber hand during the entirety of the experiment and focus as much as you can.

Do you understand the instructions?

Appendix iv: Standardized Debriefing Notes

Thank you for your participation in our experiment! Even though the study has concluded, you may still withdraw your results from the data if you choose to. This experiment aimed to evaluate the brian's connection with the prosthetic and you by manipulating the synchronization of the elicitation of the stimulus. The three groups differed based on the timing of when you felt the three objects, so one group felt and saw the stimuli together, one felt and saw them 0.5 seconds apart, and the other felt and saw them 3.0 seconds later. This allowed us to analyze how the differences in visual and tactile sensations affect one's perceived ownership over the rubber hand.

Regardless, all participants were given the same statements to respond to and experienced the same three objects (stylus, brush, ice). Once again, please let us know if you would like your results to be removed from the experiment. Thank you for your time and participation.

Appendix v: Procedure

1. Participants were taken to an empty classroom one by one where the experiment is conducted to avoid distractions and confounding variables.
2. Regardless of the group, participants are given the same instructions (see Appendix iii) and the same assent form (see Appendix ii) prior to the experiment. (NB: Parental consent forms were distributed and collected a week prior).
3. On a long desk, the participants place their left hand inside a hole of a cardboard box where the left side of the box is open for the researchers to access the hand. Their left hand isn't visible to them, allowing the rubber hand to mentally take its place.
4. Their right hand is placed on the desk in a place marked by tape so that it is parallel to a rubber hand (as realistic as possible) in front of them.
5. A blank cloth is used to cover the space between the rubber hand and their residual limb (left shoulder) so it can "connect" the prosthetic to their body and create the visual connection between the prosthetic and the participant's body.
6. After the instructions are read aloud, participants are asked to look at the rubber hand for the duration of the experiment.
7. A researcher taps the person's biological left hand and rubber hand with a stylus depending on the condition;
    a. synchronous group: tapped at the same time on the rubber and real left hand
    b. asynchronous (0.5 seconds): tapped first on biological hand followed by the rubber hand in 0.5 second intervals
    c. asynchronous (3.0 seconds): tapped first on biological hand followed by the rubber hand in 3.0 second intervals
8. Then, seven statements (Appendix vi) are read aloud to the participants to which they responded on a scale of 1-7 based on how strongly they agreed with the statement.
9. Participants were asked to wait for a period of two minutes set by a stopwatch to reduce the connection to prevent order effects.
10. Steps 6-8 were repeated twice more with two more stimuli (ie. brush and ice). (NB: stimuli are not randomized because the experiment is based on the synchronization rather than what stimuli has better results).
11. The procedure was the same and repeated for all participants.
12. All participants were then debriefed (Appendix iv).

Appendix vi: Raw Data

Synchronous condition

Participant #	Stylus	Brush	Ice	Total Average
2	5.5	6	6.75	6.08
5	3.25	4	4.75	4
8	1.25	2.75	3	2.33
11	4.75	6.5	4.75	5.33
13	4	6.5	7	5.83
14	5.5	6.75	7	6.42
17	5.5	5	6	5.5
23	4.25	6	6.75	5.77
26	7	6.25	6.5	6.58
28	6.5	6.5	7	6.67

Asynchronous (0.5 seconds) condition

Participant #	Stylus	Brush	Ice	Total Average
9	1.75	3.5	3.25	2.83
12	1	1	1.5	1.17
15	1.25	1.25	2	1.5
18	2.75	4.5	4.25	3.83
21	2	2.75	3	2.58
22	1.75	1.75	2.75	2.08
24	5	5.5	6.5	5.67
27	**2.75**	4.25	5.25	4.08
29	3.75	5	5.5	4.75
30	4.5	2.75	4.25	3.83

Asynchronous (3.0 seconds) condition

Participant #	Stylus	Brush	Ice	Total Average
3	3	3.25	4.25	3.5
4	1	1.25	1	1.08
6	1.75	1	1.25	1.33
7	1.5	1.25	1.25	1.33
10	1.25	1.75	4.25	2.42
16	3.75	4.25	2.5	3.5
19	1	3.25	4.75	3
20	1	1.25	3.25	1.83
25	2.75	3.5	3.75	3.33
31	1.75	1	2.75	1.83

Appendix vii: Statement Responses (Raw Data)

Synchronous condition

Participant #	Stylus1	Stylus2	Stylus3	Stylus4	Stylus5	Stylus6	Stylus7	Brush1	Brush2	Brush3	Brush4	Brush5	Brush6	Brush7	Ice1	Ice2	Ice3	Ice4	Ice5	Ice6	Ice7
2	6	5	6	5	1	2	7	6	6	5	7	1	1	3	7	6	7	7	3	2	4
5	1	1	6	4	1	1	1	5	1	2	5	1	1	2	5	1	5	6	1	2	3
8	2	1	1	1	1	1	1	3	3	3	2	1	1	1	2	4	2	4	1	1	1
11	6	1	7	2	2	3	4	7	5	7	7	4	5	5	5	3	6	5	4	4	5
13	5	6	2	3	1	1	1	7	7	6	6	1	1	1	7	7	7	7	1	1	5
14	5	6	5	6	7	7	5	6	7	7	7	7	7	6	7	7	7	7	7	7	6
17	7	7	5	3	1	1	1	3	7	5	5	3	1	5	7	7	5	5	3	1	5
23	5	6	2	4	6	3	1	6	4	7	7	3	4	7	7	7	6	7	5	5	7
26	7	7	7	7	1	1	1	7	6	6	6	2	2	5	7	7	6	6	5	5	7
28	6	7	7	6	3	1	2	7	6	6	7	4	3	6	7	7	7	7	6	5	7

Asynchronous (0.5 seconds) condition

Participant #	Stylus1	Stylus2	Stylus3	Stylus4	Stylus5	Stylus6	Stylus7	Brush1	Brush2	Brush3	Brush4	Brush5	Brush6	Brush7	Ice1	Ice2	Ice3	Ice4	Ice5	Ice6	Ice7
9	3	2	1	1	4	1	1	3	1	5	5	2	2	1	4	4	2	3	2	2	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1
15	1	1	2	1	1	1	2	1	2	1	1	1	1	2	2	3	1	2	1	1	2
18	3	4	2	2	5	5	1	4	3	6	5	4	7	2	4	4	5	4	6	3	2
21	2	2	1	3	5	2	1	2	2	4	3	2	5	3	3	4	2	3	2	5	3
22	2	2	2	1	1	1	1	3	2	1	1	3	2	1	4	3	2	2	2	2	3
24	4	6	5	5	2	2	1	6	6	5	5	2	2	6	7	6	6	7	2	1	7
27	3	4	2	2	4	1	1	4	3	5	5	5	2	2	6	5	5	5	3	5	3
29	3	4	4	4	2	2	1	4	4	4	3	2	5	5	5	4	6	7	2	3	1
30	4	5	4	5	2	4	1	1	3	3	4	3	2	2	4	4	4	5	2	3	3

Asynchronous (3.0 seconds) Condition

Participant #	Stylus1	Stylus2	Stylus3	Stylus4	Stylus5	Stylus6	Stylus7	Brush1	Brush2	Brush3	Brush4	Brush5	Brush6	Brush7	Ice1	Ice2	Ice3	Ice4	Ice5	Ice6	Ice7
3	1	1	6	4	1	1	1	5	1	2	5	1	1	2	5	1	5	6	1	2	3
4	1	1	1	1	2	1	3	1	2	1	1	1	1	1	1	1	1	1	1	1	1
6	2	3	1	1	2	1	1	1	1	1	1	2	1	1	1	2	1	1	2	1	1
7	2	1	1	2	1	1	1	1	1	2	1	1	1	1	1	1	2	1	1	1	2
10	1	2	1	1	1	1	1	2	3	1	1	1	1	2	4	3	5	5	3	2	5
16	3	5	2	5	1	2	1	4	2	6	5	1	1	3	2	5	1	2	1	1	2
19	1	1	1	1	1	1	1	3	2	5	3	1	1	2	5	4	5	5	4	4	6
20	1	1	1	1	1	2	4	1	1	1	2	2	1	3	1	3	3	4	4	2	3
25	3	2	4	2	5	1	4	4	3	5	2	5	2	5	4	4	4	3	2	4	4
31	1	1	2	3	1	1	1	1	1	1	1	1	1	2	1	3	3	4	2	3	4

Appendix viii: Box Plot Statistics

	Sync	Async5	Async3
lower quartile (Q_1)	5.33	2.08	1.33
upper quartile (Q_3)	6.42	4.08	3.33
IQR	1.09	2	2
median	5.8	3.33	2.13
outliers	2.33	none	none

Partial eta-squared (Fixed effects)

Inputs

F-value: 16.21 Confidence Interval: 95 %

Numerator degrees of freedom: 2 Denominator degrees of freedom: 27

Calculate Clear

It is recommended that you use the **90% CI** if you have an alpha level of 5%.

Entered values: {
":f": 16.21,
":df_effect": 2,
":df_error": 27,
":conf_int": 95
}

Results (CI using noncentral *F* distribution)

Partial eta-squared:	0.5456075	Lower limit on partial eta-squared:	0.2370625
Partial omega-squared:	0.5034757	Upper limit on partial eta-squared:	0.6844374
Cohen's *f*:	1.0069757	Lower limit on Cohen's *f*:	0.5574256
		Upper limit on Cohen's *f*:	1.4727333

Clear

Appendix ix: One-way ANOVA test and Tukey HSD Test

One-way ANOVA of your k=3 independent treatments:

source	sum of squares SS	degrees of freedom ν	mean square MS	F statistic	p-value
treatment	51.9978	2	25.9989	16.2093	2.3739e-05
error	43.3067	27	1.6040		
total	95.3045	29			

Tukey HSD results

treatments pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inferfence
A vs B	5.5407	0.0015418	** p<0.01
A vs C	7.8303	0.0010053	** p<0.01
B vs C	2.2897	0.2552446	insignificant

Appendix x: Shapiro-Wilk Test and Levene's Test

Synchronous condition

Parameter	Value
P-value	0.02966
W	0.8206
Sample size (n)	10
Average ($\bar{x}$)	5.451
Median	5.8
Sample Standard Deviation (S)	1.3418
Sum of Squares	16.2037
b	3.6466
Skewness	-1.665
Skewness Shape	**Asymmetrical**, left/negative (pval=0.015)
Excess kurtosis	2.6777
Kurtosis Shape	**Leptokurtic**, long heavy tails (pval=0.045)
Outliers	2.33

Asynchronous (0.5 seconds) condition

Parameter	Value
P-value	0.9308
W	0.9688
Sample size (n)	10
Average ($\bar{x}$)	3.232
Median	3.33
Sample Standard Deviation (S)	1.4471
Sum of Squares	18.848
b	4.2732
Skewness	0.1463
Skewness Shape	Potentially **Symmetrical** (pval=0.831)
Excess kurtosis	-0.833
Kurtosis Shape	Potentially **Mesokurtic**, normal like tails (pval=0.532)
Outliers	

Asynchronous (3.0 seconds) condition

Parameter	Value
P-value	0.1391
W	0.8817
Sample size (n)	10
Average ($\bar{x}$)	2.315
Median	2.125
Sample Standard Deviation (S)	0.9577
Sum of Squares	8.255
b	2.6979
Skewness	0.1064
Skewness Shape	Potentially **Symmetrical** (pval=0.877)
Excess kurtosis	-1.8631
Kurtosis Shape	Potentially **Mesokurtic**, normal like tails (pval=0.163)
Outliers	

Levene's Test

Groups	Sync1	Async5	Async3
Data	6.08 4 2.33 5.33 5.83 6.42 5.5 5.77 6.58 6.67	2.83 1.17 1.5 3.83 2.58 2.08 5.67 4.08 4.75 3.83	3.5 1.08 1.33 1.33 2.42 3.5 3 3.33 1.83 1.83
Skewness	-1.665041	0.146312	0.106423
Normality	0.02966	0.9308	0.1391
Outliers	2.33		
Mean	5.451	3.232	2.315
S	1.34179	1.44714	0.95772

Source	DF	Sum of Square	Mean Square	F Statistic	P-value
Groups (between groups)	2	0.8212	0.4106	0.6874	0.5115
Error (within groups)	27	16.1272	0.5973		
Total	29	16.9484	0.5844		

Appendix xi: Confidence Interval and Effect Size Calculations

Synchronous condition

Calculation steps

The mean confidence interval formula is:

$\bar{x} \pm MOE$

$$\bar{x} \pm T_{1-\alpha/2}(df) * \frac{S}{\sqrt{n}}$$

Calculate the degrees of freedom:

$df = n - 1 = 10 - 1 = 9$

Calculate the significance level:

$\alpha = 1 - CL = 1 - 0.95 = 0.05.$

Calculate the probability (p):

$p = 1 - \alpha/2 = 1 - 0.05/2 = 0.975.$

Calculate the t-score:

$T_{0.975}(9) = 2.2622$

$$\bar{x} \pm T_{0.975}(9) * \frac{1.4}{\sqrt{10}}$$

$$5.45 \pm 2.2622 * \frac{1.4}{\sqrt{10}}$$

$5.45 \pm 2.2622 * 0.4427$

5.45 ± 1.0015

Since $T_{\alpha/2} = -T_{1-\alpha/2}$, you may use $T_{\alpha/2}$ instead of $T_{1-\alpha/2}$

Asynchronous (0.5 seconds) condition

Calculation steps

The mean confidence interval formula is:

$\bar{x} \pm MOE$

$\bar{x} \pm T_{1-\alpha/2}(df) * \frac{S}{\sqrt{n}}$

Calculate the degrees of freedom:

$df = n - 1 = 10 - 1 = 9$

Calculate the significance level:

$\alpha = 1 - CL = 1 - 0.95 = 0.05.$

Calculate the probability (p):

$p = 1 - \alpha/2 = 1 - 0.05/2 = 0.975.$

Calculate the t-score:

$T_{0.975}(9) = 2.2622$

$\bar{x} \pm T_{0.975}(9) * \frac{1.44}{\sqrt{10}}$

$3.23 \pm 2.2622 * \frac{1.44}{\sqrt{10}}$

$3.23 \pm 2.2622 * 0.4554$

3.23 ± 1.0301

Since $T_{\alpha/2} = -T_{1-\alpha/2}$, you may use $T_{\alpha/2}$ instead of $T_{1-\alpha/2}$

Asynchronous (3.0 seconds) condition

Calculation steps

The mean confidence interval formula is:

$\bar{x} \pm MOE$

$\bar{x} \pm T_{1-\alpha/2}(df) * \frac{S}{\sqrt{n}}$

Calculate the degrees of freedom:

$df = n - 1 = 10 - 1 = 9$

Calculate the significance level:

$\alpha = 1 - CL = 1 - 0.95 = 0.05.$

Calculate the probability (p):

$p = 1 - \alpha/2 = 1 - 0.05/2 = 0.975.$

Calculate the t-score:

$T_{0.975}(9) = 2.2622$

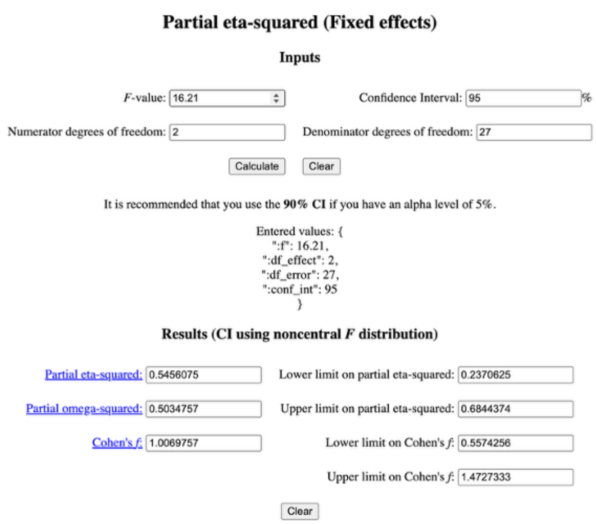
$\bar{x} \pm T_{0.975}(9) * \frac{0.95}{\sqrt{10}}$

$2.32 \pm 2.2622 * \frac{0.95}{\sqrt{10}}$

$2.32 \pm 2.2622 * 0.3004$

2.32 ± 0.6796

Since $T_{\alpha/2} = -T_{1-\alpha/2}$, you may use $T_{\alpha/2}$ instead of $T_{1-\alpha/2}$


Partial eta-squared (Fixed effects)
Inputs
F-value: 16.21
Confidence Interval: 95 %
Numerator degrees of freedom: 2
Denominator degrees of freedom: 27
Calculate
Clear
It is recommended that you use the 90% CI if you have an alpha level of 5%.
Entered values: {
":f": 16.21,
":df_effect": 2,
":df_error": 27,
":conf_int": 95
}
Results (CI using noncentral F distribution)
Partial eta-squared: 0.5456075
Lower limit on partial eta-squared: 0.2370625
Partial omega-squared: 0.5034757
Upper limit on partial eta-squared: 0.6844374
Cohen's f: 1.0069757
Lower limit on Cohen's f: 0.5574256
Upper limit on Cohen's f: 1.4727333
Clear