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Auditory-Enabled IRAP: A technical note on expanding stimulus modalities in the Implicit Relational Assessment Procedure

IRAP com Estímulos Auditivos: Uma nota técnica sobre a expansão das modalidades de estímulos no Procedimento de Avaliação Relacional Implícita

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Resumo

O Procedimento de Avaliação Relacional Implícita (IRAP) é uma ferramenta baseada na Teoria das Molduras Relacionais (RFT), que utiliza a latência de resposta para medir a força e a probabilidade de relações verbais. Esta nota técnica apresenta o IRAP com Estímulos Auditivos, uma versão adaptada do IRAP de Código Aberto, desenvolvida para incorporar estímulos auditivos à abordagem visual tradicional. Criado na plataforma PsychoPy®, este *software* permite que os pesquisadores explorem os efeitos dos estímulos auditivos nos padrões de respostas relacionais. Com a introdução de estímulos auditivos, o *software* amplia o escopo da pesquisa comportamental, abrindo novas possibilidades para estudar a dinâmica de diferentes modalidades sensoriais em tarefas relacionais. O projeto está disponível gratuitamente sob a licença GPLv3+, incentivando futuras pesquisas e adaptações. Esta ferramenta tem como objetivo a ampliação das possibilidades de pesquisa para a compreensão das respostas relacionais, facilitando a exploração de modalidades de estímulos auditivos no contexto do IRAP.

Palavras-chave: Estímulos auditivos, RFT, pesquisa comportamental, PsychoPy®, Procedimento de Avaliação Relacional Implícita (IRAP)

Abstract

The Implicit Relational Assessment Procedure (IRAP) is a latency-based tool grounded in Relational Frame Theory (RFT), used to measure the strength and probability of verbal relations. This technical note introduces the Auditory-Enabled IRAP, an adapted version of the Open Source IRAP, designed to incorporate auditory stimuli alongside the traditional visual approach. Developed using the PsychoPy® platform, this software allows researchers to explore the effects of auditory stimuli on relational responding patterns. By enabling auditory stimuli, the Auditory-Enabled IRAP broadens the scope of behavioral research, offering new opportunities to investigate the dynamics of different sensory modalities in relational tasks. The project is freely available under the GPLv3+ license, supporting further research and adaptation. This tool aims to advance the understanding of relational responding by facilitating the exploration of auditory stimulus modalities within the IRAP context.

Keywords: Auditory stimuli, Relational Frame Theory (RFT), behavioral research, PsychoPy®, Implicit Relational Assessment Procedure (IRAP)

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The Implicit Relational Assessment Procedure (IRAP; Barnes-Holmes et al., 2006) is a latency-based procedure designed to measure the relative strength or probability of verbal relations. Its theoretical foundation is rooted in Relational Frame Theory (RFT; Hayes et al., 2001), with the IRAP functioning as a tool to capture specific patterns of relational responding "in-flight" (Barnes-Holmes & Harte, 2022a). Although the IRAP was originally conceived within the behavior-analytic tradition, with the potential to further develop the RFT framework, research using the IRAP has historically employed it as a measure of "implicit cognition," often in conjunction with psychometric research strategies (Watters et al., 2023; Vahey et al., 2015). More recently, significant efforts have been made to reestablish the IRAP as a behavior-analytic instrument, shifting its focus from implicit cognition to assessing the strength and probability of natural verbal relations (Barnes-Holmes & Harte, 2022b).

Recent research has sought to identify the variables that influence participants' IRAP performance aiming not only to better understand the dynamics of the procedure itself but also to comprehend the variables that govern relational responding patterns more broadly. Several studies have underscored the importance of considering aspects such as orienting (e.g., Finn et al., 2021, 2018; Pinto et al., 2020) and evoking (e.g., Bortoloti et al., 2019, 2020, 2023) stimulus functions, and motivating variables (e.g., Gomes et al., 2020) to better account for participants' performance (Barnes-Holmes & Harte, 2022b)[1]. Additionally, it has also been acknowledged that media of contact (i.e.: the means in which a participant contacts the stimuli) is an important variable to be accounted for in IRAP studies (Harte & Barnes-Holmes, 2024).

Harte and Barnes-Holmes (2024) acknowledge that the vast majority of IRAP studies have relied solely on visual stimuli, but suggest that the IRAP could be extended to incorporate other modalities, such as auditory stimuli. We argue that the inclusion of auditory stimuli would offer a richer functional context for analyzing relational responses. By broadening the types of sensory inputs, auditory stimuli can provide new insights into how relational responding operates across different perceptual domains, thus enhancing the IRAP's effectiveness in studying the dynamics of relational responding. Additionally, auditory stimuli may capture attention differently, evoke responses that vary according to different auditory features such as prosody, and interact with motivational factors in unique ways, contributing to a deeper and more comprehensive understanding of human behavior.

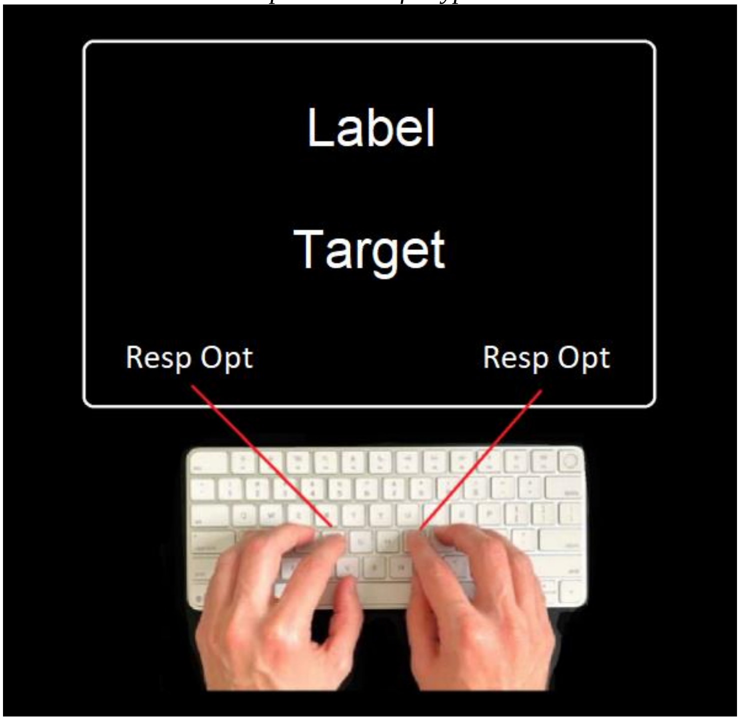
This article introduces the Auditory-Enabled IRAP software, an adaptation of the Open Source IRAP (Hussey, 2022), which now supports the integration of auditory stimuli. This advancement not only broadens the scope of research possibilities but also strengthens the IRAP's capacity to investigate relational dynamics across a wider range of sensory experiences.

The IRAP: an overview of the procedure

The IRAP is a computer-based procedure composed of several blocks of trials in which participants are required to respond to the relation between stimuli displayed on the screen. Each trial presents a label, a target, and two response options (Figure 1). Although a "similar" and "different" or "true" and "false" were employed as response options in a number of IRAP studies, they can be freely defined by the experimenter (e.g.: "same" and "opposite", "more" and "less"; see Maloney & Barnes-Holmes, 2016, for a better account on the impact of response options). The label and target stimuli in IRAP trials are typically either written words or images, and it is common for trials to have mixed formats, such as labels as images and targets as words. Labels are displayed in the upper-central section of the screen, while targets are shown in the middle-central section. The response options are typically (but not restricted to) text labels located in the bottom-left and bottom-right corners, corresponding to keys on the left and right sides of a computer keyboard (e.g., the "d" key mapped as "similar" and the "k" key mapped as "different"). It is important to note that it is possible to configure the software so that these key mappings are not fixed across trials; instead, the keys and response options can be remapped quasi-randomly.

[1] Building on recent research that emphasizes the importance of examining the interaction between relational and functional properties of stimuli in analyzing IRAP performance, Barnes-Holmes and Harte (2022b) proposed an "updated" unit of analysis within RFT, termed ROE-M. This unit encompasses four core components: relating, orienting, evoking, and motivating. Briefly, *relating* aligns with the concept of Arbitrarily Applicable Relational Responding (AARR) in RFT. *Orienting* describes the extent to which a stimulus draws attention or "stands out" within a broader context. *Evoking* pertains to the classification of a stimulus as appetitive or aversive. *Motivating* assesses the perceived strength of motivational factors, which dynamically interact with orienting, evoking, and even relating functions. The authors argue that introducing this unit allows for a deeper understanding of human behavior by conceptualizing nearly all psychological actions as complex, dynamic, and nonlinear interactions among these ROE-M components.

Figure 1
On-screen visual stimuli placement of a typical IRAP trial



Note. Response options located on each bottom-corner of the screen (e.g.: "true" and "false" or "similar" and "different") will be displayed according to the configuration set by the experimenter.

Typically, before starting each block of trials, rules which participants must follow to respond appropriately on each trial are provided. Usually, one type of block is deemed "consistent," as it aligns with the participant's presumed learning history (e.g., "respond as if flowers are positive and insects are negative"). Conversely, "inconsistent" blocks require the participant to respond contrary to their presumed learning histories (e.g., "respond as if flowers are negative and insects are positive"). Consistent and inconsistent blocks are always interleaved, requiring participants to alternate their response patterns between blocks. As a result, each ordered pair of blocks will always consist of one consistent and one inconsistent block. The order in which a block is presented within its block pair (consistent-first or inconsistent-first) can be configured by the experimenter.

It's important to note that the rules displayed before each block are completely configurable by the experimenter. For instance, they can range from long and specific instructions (like the examples given in the last paragraph) to more generic ones (e.g. "respond correctly to the stimuli" for consistent blocks and "respond incorrectly to the stimuli" for inconsistent blocks; see Finn et al., 2016, for a more detailed account on different types of instructions).

Participants are typically submitted to a practice block pair to familiarize themselves with the procedure before moving on to the test blocks (often set to 3 test blocks pairs, although configurable by the experimenter). If a participant does not achieve the desired performance (usually a mean latency of less than 2000ms and accuracy greater than 80%), they may either undergo additional practice block pairs to improve their performance or be excluded from the study. Data from practice blocks are usually not considered for final analysis (although made available by the software).

Data analysis is often employed using D-IRAP scores. In short, it involves removing outliers (usually defined as latencies above 10,000ms) then calculating the standardized mean latencies difference for each trial-type. To further illustrate, we can take the flowers and insects IRAP and its trial type 1 as an example: D-IRAP scoring algorithm will calculate the mean response latency for flower-positive trials in which participants had to respond "different" and subtracts it by the mean response latencies of the ones he had to respond "similar". This difference between those two means is then divided by the standard deviation of response latencies (i.e.: the standard deviation of response latencies from flower-positive-similar and flower-positive-different trials, combined). The same process is employed to calculate scores for all of the four trial-types, being: 1) the standardized difference between flower-positive trials 2) the standardized difference between flower-negative trials; 3) the standardized difference between insect-positive trials and; 4) the standardized difference between insect-negative trials. Resulting scores for each trial-type can be interpreted as an effect size whereas a positive score indicates participants responded faster on trials deemed "consistent" compared to trials deemed "inconsistent" and a negative score indicates the opposite: participants were able to respond faster on trials deemed "inconsistent" (see Barnes-Holmes et al., 2010, for a more detailed description of how to calculate and interpret these scores).

Since the IRAP heavily relies on response latency and consistent performance in test blocks, participants are encouraged to respond as quickly as possible while maintaining a minimum accuracy threshold, usually set at greater than 80% per block. Programmed contingencies for each block define the conditions under which corrective feedback is displayed on the screen. To illustrate, in a consistent block, responding “similar” to a flower-positive trial is considered a “correct” response (no feedback), while responding “different” to a flower-positive trial will trigger corrective feedback (typically in the form of a red ‘X’ displayed at the bottom-center of the screen). Similarly, responding “similar” to a flower-positive trial in an inconsistent block will also result in corrective feedback being displayed. The corrective feedback will remain displayed on screen until the software registers a correct response from the participant.

It is important to mention that, although other IRAP studies have employed different forms of corrective feedback other than the default red ‘X’, the presented software currently does not provide a configurable parameter for its customization by the experimenter (it can be customized, but it requires technical knowledge as it would involve editing the project’s source files). The following section explores the software and its distinct capability of employing target stimuli in auditory modality.

Auditory-Enabled Open Source IRAP: Technical Aspects

The current software was developed using the PsychoPy® platform, an open-source package widely recognized for running psychological experiments written in the Python programming language (Peirce, 2007). PsychoPy® provides a visual, largely code-free interface along with tools to design experiments and computer-based tasks for research purposes.

The Auditory-Enabled IRAP project (available at https://osf.io/nqpca) can be downloaded as a compressed audio_irap.rar file. Upon extracting its content, a folder containing several files and subfolders will be created on your computer. The main project file is named “Auditory-Enabled IRAP.psyexp” and must be opened with the PsychoPy® software (available at https://www.psychopy.org). The folder also includes a README document with relevant usage information and technical details, such as configuration files and a changelog.

Before attempting to run the project, it is important to click on the cogwheel icon (typically located in the upper-left section of PsychoPy’s interface) and set the “Use PsychoPy version” parameter to a late-2022 version such as 2022.2.5. More recent versions may also be capable of running the project if that’s desirable, but further adaptations might be required. Therefore, unless features from the most recent versions of PsychoPy are specifically needed, it is highly recommended to configure the project to use an older version (see Figure 2).

In addition to the source files, the project includes a series of WAV audio files containing vocalized words in Brazilian Portuguese. These words are positive and negative-valanced adjectives that were used as targets for its pilot study (e.g.: pleasant/unpleasant, wonderful/awful; see Rezende, 2024, for the pilot study). It’s important to note that all audio files were recorded at 48,000 Hz, as consistency in recording frequency is required for all audio files. While other audio formats may be supported, WAV is particularly recommended to ensure better quality.

When adding new customized auditory stimuli to your project, it’s crucial to consider that auditory stimuli will be emitted immediately after the intertrial interval has finished (which is set to 400ms by default). To ensure precise, simultaneous visual-auditory emission, it is essential to properly trim the length of the audio files so that no silence precedes the recorded target stimuli. This procedure is critical and must be applied to all audio files, as failure to do so could severely impact the IRAP’s performance, potentially leading to unwanted biases. For instance: given the classical flowers and insects x positive and negative IRAP, if a positive word audio file is not properly trimmed, this will lead to added latency for the trials that involve the vocalization of that specific stimulus. Figure 3 provides an example of how audio files should be recorded and trimmed.

Figure 2
PsychoPy project configuration window after clicking on the cogwheel icon

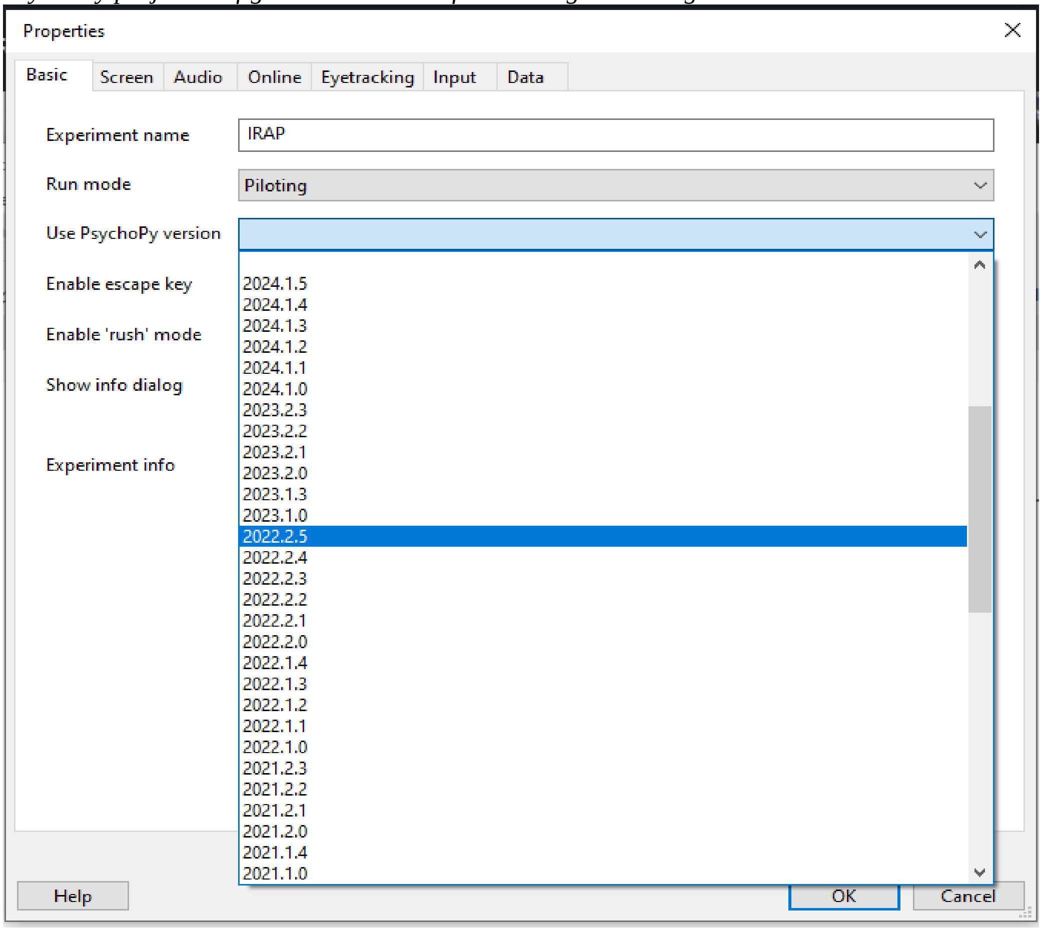
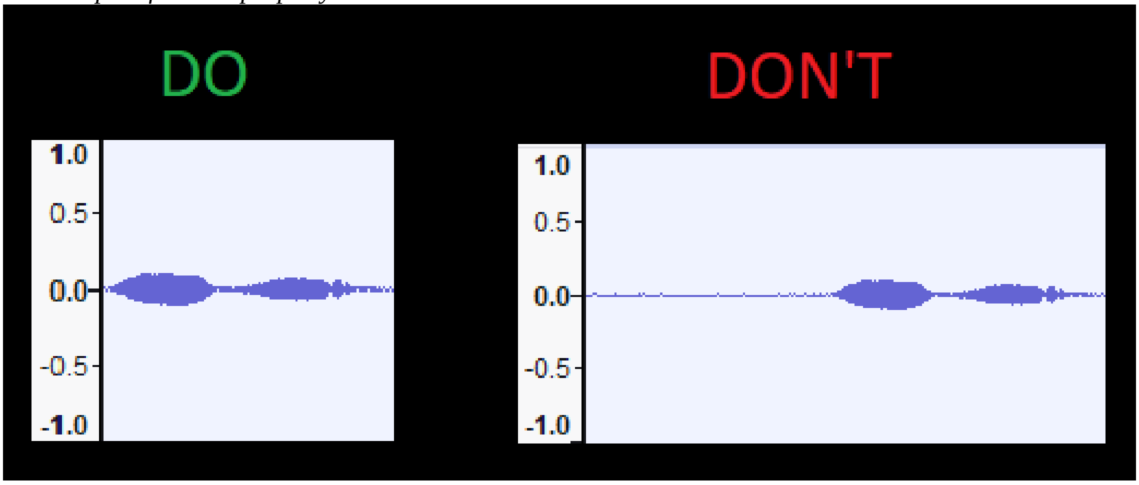
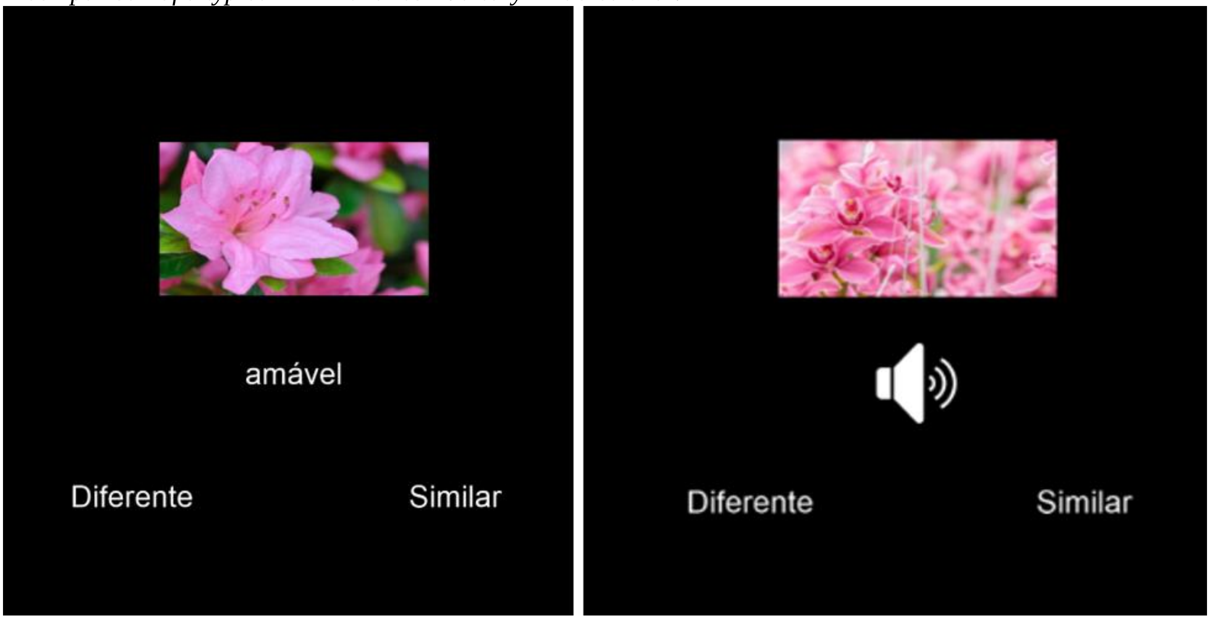


Figure 3
An example of how to properly cut recorded audio tracks in order to avoid unintended extra intertrial intervals.



Another important consideration is that, since one of the stimuli will typically be presented in the auditory modality, only one visual stimulus (the label) will be displayed on the screen across trials (see Figure 4), as opposed to the typical IRAP setup where both a label and a target are presented visually. Because the IRAP is a latency-based task and auditory stimuli inherently take time to be fully emitted compared to the immediate display of visual stimuli, the current project does not support having both the label and target stimuli in the auditory modality – only target stimuli can be set in auditory modality. Doing so would likely mischaracterize the IRAP's core nature as a latency-based procedure.

Figure 4
A comparison of a typical IRAP trial vs Auditory-Enabled trial.



Note. The target-stimuli, nor the speaker icon, is displayed on the Auditory-Enabled IRAP as they are vocalized instead. The images show the label stimulus "amável" and two response options "diferente" and "similar", which mean "lovely", "different" and "similar", respectively. Although words in Brazilian Portuguese are shown, the software bears no language restriction. Labels, targets and response options are configurable by the experimenter, and can be set in any language. However, only targets can be set as auditory stimuli.

A pilot study that employed the auditory-enabled IRAP software was conducted by Rezende (2024). Three groups were submitted to a) control typical IRAP; b) auditory-enabled IRAP and; c) auditory-enabled IRAP with emotional intonation (positive-valanced target stimuli were recorded with a positive-valanced emotional intonation, whilst negative-valanced with negative-valanced emotional intonation). Coherent with recent literature, results revealed the Single Trial-Type Dominance Effect (STTDE) – observed D-IRAP scores for trial type 1 were the largest ones for all three groups (Finn et al., 2018). However, attenuated trial type 1 scores were observed on both b and c auditory groups ($M_{auditory} = 0.4$, $SE_{auditory} = 0.075$; $M_{emotional} = 0.4$, $SE_{auditory} = 0.075$) compared to control group ($M_{control} = 0.61$, $SE_{control} = 0.069$). Except for trial type 1, no other significant difference was observed across neither groups nor trial types.

Finally, the project files also include an R script file that can be executed using RStudio software (see RStudio Team, 2020) to calculate D-IRAP scores from data contained in .csv files, which are automatically generated when a participant completes the task. As described in the previous section, D-IRAP scores quantify the differences in response latency between presumed consistent and inconsistent blocks. There is no particular aspect regarding calculating scores from IRAPs with auditory targets compared to traditional IRAPs.

Conclusion

The present technical note has sought to introduce a modified version of the IRAP software that supports auditory stimuli as targets. A pilot study suggests that the procedure with auditory stimuli is able to yield similar results to typical IRAPs – despite the observed STTDE being not as strong as the one reported by Finn et al. (2018). It is still unclear whether this attenuated effect was due to, for instance, trials with auditory stimuli being able to achieve better stimulus control, or if it could be explained solely by the non-immediate nature of an auditory stimulus emission.

Although recorded words can be fully vocalized in less than a second, it could be argued that using auditory stimuli might attenuate the magnitude of computed D-IRAP scores compared to those generated from typical IRAP studies. However, preliminary data from an in-house experiment suggest that participants can theoretically achieve mean latencies as low as 600ms within consistent blocks of single-word auditory trials (Rezende, 2024). It is also worth noting that minimum mean latencies registered on these auditory IRAPs did not differ significantly from minimum mean latencies registered from the control typical IRAP group.

Yet, it could be the case that achieving such low-latency responses may be more challenging compared to typical immediately-displayed visual trials with written words and/or pictures. If that is the case, the frequency in which low latencies are achieved by participants in auditory IRAPs may have a significant influence on the final calculated score for trial type 1, thus attenuating the observed STTDE. Nonetheless, while the D-IRAP scoring algorithm is widely used, it is not the only method of analysis applicable to IRAP data (De Schryver et al., 2018; Harte et al., 2021). Future research is encouraged not only to replicate known effects using an auditory stimulus modality, but also to explore new methods of analysis that may prove more suitable for the Auditory-Enabled IRAP.

Auditory stimuli are less commonly used in computer-based behavioral tasks, with visual displays combined with tactile inputs such as keypresses or mouse clicks being the dominant approach. We believe that further research involving auditory-enabled behavioral tasks could provide valuable insights into our field of study, and we hope this project encourages additional investigations into the specific effects of this stimulus modality.

The Auditory-Enabled IRAP is released under the GPLv3+ open-source license without any warranty. It is a free software, and anyone may redistribute and/or modify it under the terms of the GNU General Public License version 3 or any later version.

Declaração de conflito de interesses

Os autores declaram que não há conflito de interesses relativos à publicação deste artigo.

Contribuição de cada autor

Certificamos que todos os autores participaram suficientemente do trabalho para tornar pública sua responsabilidade pelo conteúdo. A contribuição de cada autor pode ser atribuída como se segue: WCC concebeu e desenvolveu o software e redigiu a primeira versão deste manuscrito; GCPR concebeu o projeto, aplicou o software em estudos experimentais e colaborou na redação do manuscrito; RB colaborou na redação do manuscrito e supervisionou o projeto como um todo.

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