On the cyclic nature of auditory perception:

Does neural entrainment cause fluctuations in target detection performance?

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Abstract

Perception of exogenous stimuli is a less linear process than it was long thought of. Instead, recent research suggests a rhythm adapting oscillatory mechanism in perception, called neural entrainment. This within-subjects study (*N* = 17) takes a closer look at the idea of an endogenous oscillatory mechanism in auditory perception, replicating a study by L'Hermite & Zofel (2023). By using a target tone detection task, after being confronted with two rhythmic entrainment stimuli, we investigated whether neural entrainment led to temporal fluctuations in target detection performance. We hypothesized, that detection of expected stimuli peaks in-phase with the entrainment rhythm, whereas detection of unexpected stimuli peaks anti-phase. To evaluate such entrainment effects, we compared the detection performance of eight timeslots (delays), with varying distances from the course of the entrainment rhythm. No such effects of target tone delay on detection rate were found for any of the conditions. Due to insufficiencies in the presentation volume, the results ask for replication under improved conditions. With this study no further evidence for an endogenous cyclic nature of auditory perception could be contributed. Still, this study's approach, consistent with previous experiments, raises questions about the underlying mechanisms of human's perceptual system and discusses the plausibility of an oscillatory nature.

Keywords: neural entrainment, entrainment echoes, auditory perception, cyclic perception

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Perception of stimuli through the sensory system is one of the most essential functions of all living creatures, as it enables to interact with the environment. Still, the underlying mechanisms of perception are not yet completely understood and have long been a subject of scientific inquiry. Humans experience perception as a linear continuous process, and for a long time, the brain was viewed as passive in this process, simply transforming and processing bottom-up information from the senses (Engel et al., 2001). In the last decades however, a new perspective on the brains role in perception has spread. Many experiments have found evidence that the brain is not at all passive but plays an active role in the process of perception not only processing bottom-up information but also using top-down information about past experiences to form predictions about future events (Engel et al., 2001; Ho et al., 2019). Even more: not only the processing of sensory information but also the sensory system itself is less linear than long assumed, simply passing on sensory information to the brain. Instead, neurons have been found to adapt to rhythmic structures in the environment and adjust perception to it (e.g., Spaak et al., 2014; VanRullen et al., 2014; Hickok et al., 2015; L'Hermite & Zofel, 2023). This phenomenon is called neural entrainment (Lakatos et al., 2019).

Entrainment in a general sense means the rhythmic adjustment of an oscillatory process to an exogenous rhythm (Lakatos et al., 2019). While temporal alignment of exogenous stimuli and endogenous brain activity is rather easy to find, it is still a subject of discussion which inferences can be drawn from this (Obleser & Kayser, 2019). Temporal alignment of brain activity with oscillatory stimuli could either be a phenomenon of resonance, caused by a cascade of evoked responses from the series of sensory inputs or the result of an underlying endogenous oscillatory mechanism in the perceptual system itself

(Obleser & Kayser, 2019; L'Hermite & Zofel, 2023). If the perceptual system really had an endogenous oscillatory mechanism instead of impulse-like evoked responses, the alignment with external rhythm should not stop with the offset of the stimuli but persist for some time after being entrained before returning back to its own oscillation frequency (Spaak et al., 2014; Obleser & Kayser, 2019; Lakatos et al., 2019; L'Hermite & Zofel, 2023).

To collect evidence for this endogenous oscillatory mechanism in auditory perception and the effect of neural entrainment on it is the goal of this study, which is based on an experiment by L'Hermite & Zofel from 2023.

In our experiment, participants were presented with two rhythmic entrainment sounds simultaneously (a high and a low one) followed by a target tone, which they should detect. Participants were asked to attend to one of the entrainers while ignoring the other one. Following the idea of neural entrainment, we expected the entrainment rhythm to echo in the perceptual system and cause rhythmically aligned fluctuations in the detection rate. L'Hermite & Zofel (2023) proposed, that entrainment was organized according to sound frequency. Following this idea, we focused on trials with the high entrainer attended and hypothesized that perception of the high target tone should peak when being presented in-phase with the entrainment stimuli, as this is the stimuli participants were entrained with and therefore expect aligned with the rhythm. Perception of the low target tone was assumed to peak anti-phase when expectation for the high target tone is lowest.

With this design, the experiment could collect further evidence, that (1) perception is endogenously rhythmic and (2) adapts to exogenous rhythmic structures, temporally sharpening perception at timepoints where events are predicted.

Methods

Participants

17 participants were recruited for this study. Most of the participants were psychology students at Goethe University Frankfurt Germany and were recruited via the internal platform Sona Systems (online access: https://uni-frankfurt.sona-systems.com/). They were given credit for participating. External participants were recruited using this online link: https://moryscarter.com/ vespr/ pavlovia.php?folder=akiai&experiment=rhythmic_entrainment/&researcher=akiai.

After obtaining informed consent, the data of the participants was collected anonymously. For analysis, each participant was assigned a participant ID which does not allow for inferences about the individual.

Material

The experiment was programmed in PsychoPy (v.2021.2.3; Peirce et al., 2019) and hosted on Pavlovia server (online access: https://gitlab.pavlovia.org/akiai/rhythmic_entrainment). As entrainers, two pure tones were used, one with a frequency of 1200 Hz, the other one with a frequency of 500 Hz. Each of them had 5 cycles (duration < 1s). Based on findings by L'Hermite & Zofel (2023) the amplitude modulation rate (AM) was set to 6 Hz, as this rate was expected to have the strongest entraining effect. As target tones two pure tones with the same frequencies as the entrainers, 500 Hz and 1200 Hz, were used but with only 0.25 cycles of the presentation rate. Participants were asked to make use of their own laptop (not a mobile device) and use headphones. A Preregistration, using an AsPredicted template, was published on the local infrastructure for open science (LIFOS) of Goethe University Germany on 22nd of January 2024. The study was accepted by the ethics committee of the Psychology Department of Goethe University Frankfurt Germany. Supplementary materials such as the preregistration, data, and R code, were made public on LIFOS Goethe University website (link for online access: see Appendix A).

Procedure

At first, acoustic noise was presented for participants to set volume to a comfortable level. Then, a Huggins Pitch test by Milne et al. (2021) was used to ensure that participants were wearing headphones. Participants who failed this test were excluded from analysis. Afterwards, a sound check using adaptive staircase procedure was conducted, measuring the hearing thresholds for both the high and the low pure tone separately This should grant, that the target tones were presented at hearing threshold with around 50% mean detection probability. Then, participants were given one practice trial to get familiar with the experiment.

At each trial, participants were presented the two entrainers (1200 Hz and 500 Hz, AM = 6 Hz, 5 cycles) simultaneously at comfortable volume. The participants were asked to focus attention on one of them, while ignoring the other one. The selection of the attended entrainment was unpredictable for the participants. Afterwards, they were presented either the high (1200 HZ) or the low (500 Hz) target tone at almost hearing threshold or no target tone at all. These target tones were presented randomly at one of eight possible time slots, called delays, referring to the time between the final cycle of the entrainer and the target tone. These delays were either closer to the oscillation cycles of the entrainer sound (in-phase) or further apart from it (anti-phase). The eight delays started at 1.75, increasing by steps of 0.25 cycles up to 3.5 cycles apart from the entrainer in the presented oscillation rate (6 Hz).

The sounds were presented in eight blocks. Each block consisted of 192 trials, presenting each of the 48 combination of variables (3x8x2) four times, resulting in 64 trials of each target tone and 64 trials with no target tone per block. Each participant was presented all combinations of conditions in random order.

After each trial participants were confronted with a 3-AFC (Answer Forced Choice) with the options “same”, “different” or “none” referring to the attended entrainer and the target tone. “None” meant that they heard no target tone after the entrainer, “same” meant the target tone matched the attended entrainer, “different” meant the target tone did not match the attended sound stream (but the unattended one). When a target tone was present, the answers “same” and “different” were both coded as target tone perceived (hit).

Our hypothesis only refers to trials when the high entrainer was attended and a target tone was presented, therefore we focus on this condition.

Design

The experiment followed a 2x3x8 multifactorial within-subjects design. The two entrainment sounds (500 Hz and 1200 Hz), three possible target tone conditions (high, low, none) and eight delays served as independent variables (IV). For our hypothesis we focused on trials when the high entrainer was attended and a target tone was present. Therefore, our independent variables reduced to a 2x8 combination of the two target tones (high, low) and eight delays. The detection rate, meaning the proportion of perceived target tones (hits) compared to missed target tones (misses), served as dependent variable (DV).

Analysis

To analyze the data, we used R (version 4.3.2; R Core Team, 2023) and RStudio (version 23.06.1; RStudio Team, 2020) with the packages "tidyverse", "ggpubr" and "rstatix". First, general descriptive statistics such as means (*M*) and standard deviations (*SD*) of the independent variable were calculated for the whole data set as well as subsets of the data. Precisely, the dataset was reduced to only trials when the high entrainer was attended and a target tone was present and then further divided in subsets for the trials with high and trials with low target tone, A Wilcoxon rank-sum test for paired samples was conducted to test differences in detection rate between the high versus low target tone condition.

To test our hypothesis, we planned to execute an 8x2 two-way repeated measure ANOVA to investigate the main effects of the eight target delays and the two target tones on detection rate and possible interactions between the independent variables. Afterwards, calculation of effect size using Kendall's *W* (*W)* as well as post-hoc comparisons (Wilcoxon rank-sum test) should be conducted to identify the target delays that differed in detection rate and plot them to see whether they followed our expected course. To justify ANOVA we conducted assumption tests for the data. To identify outliers, we used box plot methods as well as R-intern functions. To test for normality, we used the Shapiro-Wilk test as well as visual inspection using QQ plots. To test for sphericity, we used Mauchly's Test.

Because all of the assumptions for ANOVA were violated, we used a nonparametric alternative, two one-way Friedman's tests, renouncing the analysis of interactions, to test for significant differences of detection rate between the delays. The Friedman's tests were run for the subsets of the two target tones separately. Then, calculation of effect size (*W)* as well as post-hoc comparisons (Wilcoxon rank-sum test), using a Bonferroni correction to prevent alpha error inflation, were conducted.

Due to an overly high overall detection rate, we conducted analysis again with a subset of participants, excluding participants with a mean detection rate of over 90%. This led to exclusion of ten participants while seven remained for further analysis.

The used R code for this analysis can be viewed at LIFOS Goethe University (online access: see Appendix A).

Results

For the whole dataset, the detection rate was $M = 0.63$ ($SD = 0.48$). The subset of trials with the high entrainer attended and target tone present showed an unexpectedly high detection rate of $M = 0.83$ (*Median* = 0.94, $SD = 0.23$; see Figure 1). As tones should be presented at hearing threshold, we expected the mean detection rate to be around 0.5. The subsets of target high and target low conditions showed means of $M = 0.80$ ($SD = 0.27$) for the low target tone and $M = 0.87$ ($SD = 0.17$) for the high target tone in the detection rate (for summary statistics of all combinations of IV's see Table B1, Appendix B). The Wilcoxon rank-sum comparison between the target tone conditions showed better target detection performance for the high target tone with moderate effect ($V = 1238$, $p < 0.01$, $W = 0.36$). The means of detection rate for each delay of both conditions is shown in Figure 2.

Figure 1

Overall detection performance across all trials

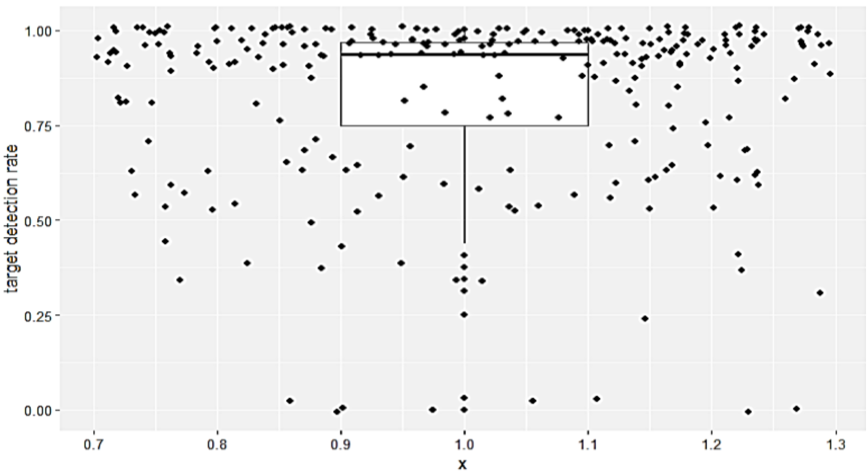
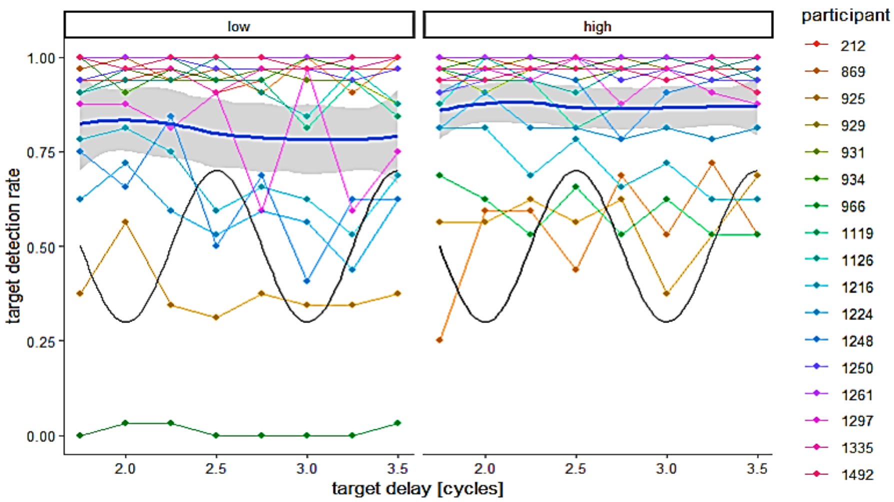


Figure 2

Target detection rates for all delays and target tones



The assumptions tests showed that all assumptions for ANOVA were violated. 19 outliers could be identified by visual as well as statistical inspection. Normality tests showed that the data was not normally distributed in any of the cells (Shapiro-Wilk test in all cells: $p < 0.01$). Mauchly's test showed that sphericity was not given ($p < 0.01$).

Therefore, a nonparametric alternative, two one-way Friedman's tests, was conducted instead, which showed no significant effect of the delays on detection rate for either the subset of the high ($p = 0.807$, $W = 0.03$) or the low ($p = 0.086$, $W = 0.10$) target tone (Table 1). Still, post-hoc comparisons were conducted showing no differences between the target delays for either of the target tone conditions when correcting for alpha error inflation (adjusted $p > 0.05$ for all cells; see Tables B2 and B3, Appendix B). When plotted, our data did not show the expected course of in-phase peaks of detection rate for the high and anti-phase peaks for the low target tone (Figure 2).

Table 1

Friedman's test for target high and low condition

target	**y**	***n***	**statistic (*V*)**	***df***	***p***	**Kendall's *W***	**magnitude**
low	detection rate	17	12.476	7	0.086	0.105	small
high	detection rate	17	3.757	7	0.807	0.031	small

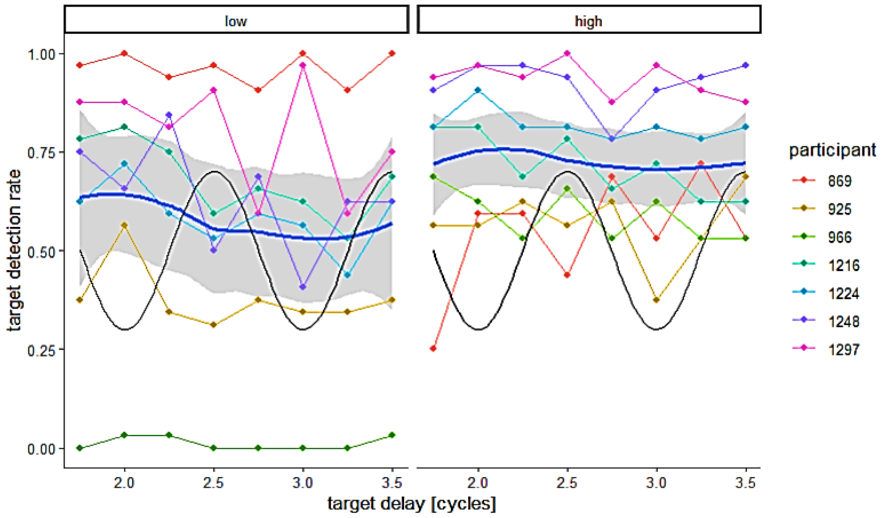
Note: n = sample size, *df* = degrees of freedom

When executing analysis again with the subset of participants (M detection rate < 0.9), the new mean of detection rate was $M = 0.65$ ($SD = 0.26$), which is closer to our aimed for mean of 0.5 (means for all combinations of IV's: Figure 3).

When executing the Friedman's tests again with the subset of participants, the target low condition showed a moderate effect of the delays on detection rate ($V = 21.51$, $p = 0.003$, $W = 0.44$) while the target high condition remained unsignificant ($V = 9.15$, $p = 0.242$). The post-hoc comparison for the low condition however showed no significant differences in detection rate (adjusted $p > 0.05$ for all groups), when correcting for alpha error. The plot of this data shows more curve fluctuation than before, but still not our expected course as described above (Figure 3).

Figure 3

Target detection rates for the subset of participants



Discussion

Summary of results and limitations

With this experiment we tried to collect further evidence for the intrinsically cyclic nature of auditory perception and the effect of neural entrainment on it. Precisely, we hypothesized that detection rate would be better in-phase with the entrainment cylces for expected stimuli (frequency matching the entrainer) and better anti-phase for unexpected ones (frequency differs from entrainer). This hypothesis did not hold true as our data did not show effects of the target delays on detection performance and no differences between the individual delays for either of the conditions.

A central prerequisite for this study was the presentation of target tones at hearing threshold, to test for fine differences in the detection performance between the conditions. We tried to achieve this by using the soundcheck at the beginning of the experiment. However, because of the overly high detection rate of 94% (Median; *M* = 0.83), the soundcheck presumably did not work accurately for most of the participants and target tones were presented too loudly. Due to this circumstance, we were not able to test for such differences in the detection rate, as almost all target tones were detected independent of trial condition. When conducting analysis with a subset of participants for which the soundcheck seemed to work, we were able to find effects of target delay on the detection rate for the low condition but relying on the data of seven participants this should rather be seen as a suggestion, not a definite scientific result. Further research with a bigger population of participants under laboratory conditions, granting appropriate sound conditions, could help to yield more reliable results.

The role of entrainment in perception

Although our findings are not able to contribute further evidence to the idea of cyclic perception, previous research found evidence for this theory. The experiment of L'Hermite & Zofel (2023) could show persisting entrainment echoes in the auditory perceptual system, which influenced participant's target detection performance, which speaks for endogenous rhythmic processes involved, consistent with other findings (e.g. Spaak et al., 2014; Hickok et al., 2015; Obleser & Kayser, 2019;).

Cyclic processes could not only be shown for acoustic but also e.g. visual perception at a rate of 7-8 Hz (VanRullen, R., 2013; VanRullen et al., 2014; Fiebelkorn et al., 2013, Albouy et al., 2022), indicating that diverse perceptual processes share an underlying oscillatory structure. Even more, interactions between these sensory processes can be assumed, as Albouy et al. (2022) found visual rhythmic stimulation enhancing auditory memory performance and Schmidt et al. (2007) could show connections between visual rhythmic stimulation and motoric coordination.

Because perception is mandatory in most human abilities, underlying rhythmic processes should also show in practical tasks. For example, neural entrainment in auditory perception is discussed as the underlying mechanism of humans capability to understand rhythmic structures in music, identifying beat and harmonics (Tal et al., 2017; Tierney & Kraus, 2015). Also in speech perception, perceptual neuron's ability to detect rhythmic patterns is discussed as a key mechanism to detect speech and create meaning from it, serving as a filter to distinguish between important and unimportant sensory input (Obleser & Kayser, 2019) as e.g. differentiating voice from background noise. Kösem et al. (2018) showed that auditory entrainment, caused by modulation of speech rate when presenting a spoken sentence, led to shifting perception of ambiguous words, suggesting semantic predictions based on rhythmic linguistic patterns. These exemplary findings show that oscillatory perceptual processes are not limited to abstract laboratory experiments but also show in more realistic scenarios and present a possible explanation for human's complex perceptual abilities.

As perception is such a complex process, most likely a combination of various processes is involved to create perceptual representations. The influence of top-down attention (e.g. focusing on one of the two entrainers while ignoring the other one) in the entrainment process (L'Hermite & Zofel, 2023; Obleser & Kayser, 2019) is a good example to assume that both top-down processes, as well as bottom-up information is combined to optimize perception. These processes seem to be in hierarchical order, traveling along feedback paths from higher to lower areas (Obleser & Kayser, 2019): inferences drawn from bottom-up sensory input lead to predictions about the future, focusing the perceptual system on where subjectively relevant stimuli are most expected. This process of prediction from exogenous patterns is what could be seen as entrainment echoes, sharpening perception on timepoints within the perceived exogenous rhythm (L’Hermite & Zofel, 2023). This integration of information from different hierarchical levels might create our sense of perception. Taking the example of speech perception, top-down driven attention to the speaker might be the first step in the hierarchical order followed by the combination of various bottom-up information from e.g. auditory entrainment, adapting to the rhythmic structure of words or syllables (Kösem et al., 2019), but also entrainment to rhythmic visual information as lip movement (Hauswald et al., 2018). Furthermore, additional information as spatial information (from where the sound is coming) or semantic information are integrated (Obleser & Kayser, 2019) and contribute to the perceptual representation. Therefore, neural entrainment alone is not sufficient to explain perceptual representation but might be one underlying key mechanism that allows to process exogenous information and optimize perception for the respective context.

Open questions and future directions

Despite the compelling previous findings regarding rhythmic mechanisms in sensory perception as presented above, many questions remain unanswered and ask for further research. Although entrainment processes in the brain could be shown in many studies as stated above and these entrainment processes might be selective to specific information (e.g. pitch: L’Hermite & Zofel, 2023; or linguistic patterns: Kösem et al., 2018), further investigation is needed on which brain areas are sensitive for entrainment of which information and how this information is then combined. Also, it remains unclear which significance rhythmic entrainment information really holds in the hierarchy of information and when it becomes behaviorally relevant, as whether it can reflect a perceptual outcome alone or mostly is rather just a physical attribute of sensory information. To further understand these complex interactions and combinations of different kinds of information for creating a perceptual representation of environment, and entrainment's role in this process, remains a goal for future research.

Finally, by understanding the role of entrainment in the human brain and where it becomes behaviorally relevant, this knowledge of influencing brain activity with external stimuli could be used to actively enhance cognitive functions of oscillatory nature, using the brain-intern adapting capabilities. Promising results of this approach could already be shown for sleep (Abeln et al., 2014) or memory (Hanslmayr et al., 2019; Albouy et al., 2022) and might be a compelling field for future research.

Although this experiment could not provide further evidence for an endogenous oscillatory nature of auditory perception and neural entrainment mechanisms, such cyclic processes seem to be one of the most promising explanations for human's perceptual abilities and the cognitive representation of exogenous patterns.

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Appendix A

Online access to supplementary material

Supplementary material such as the preregistration, the stimuli, the data, and the R code used can be viewed at LIFOS Goethe University: https://LIFOS.uni-frankfurt.de/psybsc10-empirisch-experimentelles-praktikum-ws23-24/allgemeine-psychologie-i-kiai/attention-in-auditory-entrainment-and-its-effects-on-perception

Appendix B

Tables for summary statistics and posthoc comparisons

Table B1

Summary statistics for all combinations of IV's

Target	**delay**	***n***	**min**	**max**	**median**	**iqr**	**mean**	***sd***	***se***
low	1.75	17	0.000	1	0.906	0.219	0.822	0.268	0.065
low	2.00	17	0.031	1	0.938	0.156	0.840	0.246	0.060
low	2.25	17	0.031	1	0.938	0.188	0.829	0.271	0.066
low	2.50	17	0.000	1	0.938	0.375	0.789	0.295	0.071
low	2.75	17	0.000	1	0.938	0.312	0.790	0.276	0.067
low	3.00	17	0.000	1	0.969	0.344	0.787	0.297	0.072
low	3.25	17	0.000	1	0.938	0.375	0.772	0.297	0.072
low	3.50	17	0.031	1	0.875	0.312	0.794	0.265	0.064
high	1.75	17	0.250	1	0.938	0.156	0.855	0.195	0.047
high	2.00	17	0.562	1	0.938	0.062	0.888	0.148	0.036
high	2.25	17	0.531	1	0.969	0.156	0.875	0.160	0.039
high	2.50	17	0.438	1	0.938	0.188	0.869	0.172	0.042
high	2.75	17	0.531	1	0.938	0.188	0.860	0.154	0.037
high	3.00	17	0.375	1	0.969	0.188	0.868	0.191	0.046
high	3.25	17	0.531	1	0.969	0.188	0.871	0.167	0.041
high	3.50	17	0.531	1	0.938	0.188	0.869	0.169	0.041

Note: n = sample size, iqr = interquartile distance, *sd* = standard deviation, *se* = standard error

Table B2

Results of posthoc analysis for target high condition

y	delay1	delay2	*n1*	*n2*	statistic	*p*	adjusted *p*	significance
detection rate	1.75	2	17	17	23.0	0.217	1	not significant
detection rate	1.75	2.25	17	17	19.0	0.411	1	not significant
detection rate	1.75	2.5	17	17	24.5	0.256	1	not significant
detection rate	1.75	2.75	17	17	51.0	0.725	1	not significant
detection rate	1.75	3	17	17	27.5	0.653	1	not significant
detection rate	1.75	3.25	17	17	34.5	0.746	1	not significant
detection rate	1.75	3.5	17	17	37.5	0.596	1	not significant
detection rate	2	2.25	17	17	43.0	0.392	1	not significant
detection rate	2	2.5	17	17	65.0	0.437	1	not significant
detection rate	2	2.75	17	17	56.0	0.193	1	not significant
detection rate	2	3	17	17	27.0	0.230	1	not significant
detection rate	2	3.25	17	17	73.0	0.470	1	not significant
detection rate	2	3.5	17	17	43.5	0.369	1	not significant
detection rate	2.25	2.5	17	17	49.0	0.831	1	not significant
detection rate	2.25	2.75	17	17	31.0	0.334	1	not significant
detection rate	2.25	3	17	17	38.0	0.968	1	not significant
detection rate	2.25	3.25	17	17	38.5	0.647	1	not significant
detection rate	2.25	3.5	17	17	28.0	0.539	1	not significant
detection rate	2.5	2.75	17	17	53.5	0.597	1	not significant
detection rate	2.5	3	17	17	55.0	0.898	1	not significant
detection rate	2.5	3.25	17	17	37.0	0.754	1	not significant
detection rate	2.5	3.5	17	17	46.0	1.000	1	not significant
detection rate	2.75	3	17	17	32.0	0.358	1	not significant
detection rate	2.75	3.25	17	17	17.5	0.582	1	not significant
detection rate	2.75	3.5	17	17	25.0	0.496	1	not significant
detection rate	3	3.25	17	17	75.0	0.727	1	not significant
detection rate	3	3.5	17	17	41.0	0.496	1	not significant
detection rate	3.25	3.5	17	17	28.5	0.958	1	not significant

Note: n = sample size, adjusted *p* used Bonferroni correction

Table B3

Results of posthoc analysis for target low condition

y	delay1	delay2	*n1*	*n2*	statistic	*p*	adjusted *p*	significance
detection rate	1.75	2	17	17	30.0	0.285	1	not significant
detection rate	1.75	2.25	17	17	44.5	0.623	1	not significant
detection rate	1.75	2.5	17	17	57.0	0.166	1	not significant
detection rate	1.75	2.75	17	17	43.5	0.109	1	not significant
detection rate	1.75	3	17	17	72.5	0.214	1	not significant
detection rate	1.75	3.25	17	17	60.0	0.103	1	not significant
detection rate	1.75	3.5	17	17	52.0	0.093	1	not significant
detection rate	2	2.25	17	17	47.5	0.525	1	not significant
detection rate	2	2.5	17	17	82.0	0.063	1	not significant
detection rate	2	2.75	17	17	55.5	0.046	1	not significant
detection rate	2	3	17	17	62.0	0.076	1	not significant
detection rate	2	3.25	17	17	82.5	0.058	1	not significant
detection rate	2	3.5	17	17	69.0	0.020	0.546	not significant
detection rate	2.25	2.5	17	17	69.0	0.104	1	not significant
detection rate	2.25	2.75	17	17	69.0	0.017	0.468	not significant
detection rate	2.25	3	17	17	64.0	0.201	1	not significant
detection rate	2.25	3.25	17	17	43.0	0.017	0.473	not significant
detection rate	2.25	3.5	17	17	63.5	0.057	1	not significant
detection rate	2.5	2.75	17	17	23.0	0.679	1	not significant
detection rate	2.5	3	17	17	42.5	0.860	1	not significant
detection rate	2.5	3.25	17	17	38.0	0.686	1	not significant
detection rate	2.5	3.5	17	17	42.0	0.833	1	not significant
detection rate	2.75	3	17	17	52.0	0.671	1	not significant
detection rate	2.75	3.25	17	17	32.5	0.251	1	not significant
detection rate	2.75	3.5	17	17	38.5	1	1	not significant
detection rate	3	3.25	17	17	43.0	0.782	1	not significant
detection rate	3	3.5	17	17	40.0	0.441	1	not significant
detection rate	3.25	3.5	17	17	27.5	0.384	1	not significant

Note: *n* = sample size, adjusted *p* used Bonferroni correction

Declaration of Authorship

I hereby declare that I have independently authored the present work, without recourse to sources or aids other than those specified. Direct quotations or excerpts thereof are duly acknowledged as citations, while other adaptations in terms of content and scope are appropriately credited. I have tackled the assignment alone and without consultation with others. This work has not been submitted to any examination authority in identical or similar form, nor has it been published elsewhere. It has not been, either in part or in whole, utilized for any other examination or academic purpose.

Place and date: Signature: S. Schaugg
Frankfurt am Main, March 4th 2024 (Simon Schaugg)