Abrupt vs. gradual visual onsets in go/no-go sustained attention tasks

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Abstract

Two experiments compared both average performance and changes in performance across time in abrupt- and gradual-onset sustained attention tasks. Experiment 1 compared abrupt- and gradual-onset digits. In conditions where the digits onset and offset abruptly and appeared only briefly, similar to typical conditions in the Sustained Attention to Response Task (SART), participants committed more errors on no-go trials and responded faster overall, indicative of a shift in the speed/accuracy tradeoff toward speed. When the digits abruptly onset but remained on-screen for a longer period of time, there were no differences in no-go error rates, hit rates, or reaction time (RT) variability, but participants still emitted faster RTs overall. Experiment 2 compared abrupt- and gradual-onset images. Similar to Experiment 1, abrupt-onset, short-duration images induced more no-go errors and faster RTs, but also more RT variability and reduced hit rates. In the abrupt-onset, long-duration condition, again the only performance difference was a decrease in average RTs. We discuss implications for using these two types of tasks in sustained attention research.

Keywords: sustained attention; vigilance; abrupt onsets; continuous performance

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Abrupt vs. gradual visual onsets in go/no-go sustained attention tasks

Sustaining attention to a single task for a long period of time can be difficult. One of the most robust effects in cognitive psychology is the vigilance decrement, a worsening of performance across time in tasks that demand continuous and sustained attention (see Esterman & Rothlein, 2019 for a recent review). Historically, sustained attention (or vigilance) tasks have used low target frequencies, as they were developed to mimic scenarios in which important events occurred rarely amid sequences of frequent non-target events (e.g., radar monitoring; Mackworth, 1948). Thus, in traditional sustained attention tasks, the large majority of non-target trials require no response, whereas a small minority of target trials require responses. Robertson, Manly, Andrade, Baddeley, and Yiend (1997) flipped these response probabilities, requiring frequent target responses and rare withholding of responses on non-target trials. Using these respective response probabilities, Robertson et al. (1997) found that withholding responses on the relatively rare non-target trials was particularly difficult, as the *go* response becomes habitual and must be overridden when rare *no-go* trials occur. Since Robertson et al. (1997) published this seminal study, it has been cited nearly 2,000 times and used in dozens if not hundreds of studies. Researchers have used the SART to investigate individual differences in executive attention (e.g., McVay & Kane, 2009, 2012), the neural correlates of attentional lapses (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009), and clinically-significant executive functioning deficits associated with traumatic brain injury and psychopathology (Chan & Chen, 2004; Robertson et al., 1997).

The SART carries one important feature: the *go* and *no-go* stimuli abruptly onset and offset. In the original study by Robertson et al. (1997), participants were asked to respond any time a single digit other than the number 3 appeared. Each digit 1 - 9 appeared with equal frequency (89% *go*, 11% *no-go* trials). Importantly, the digits appeared for only 250 ms, followed by a 900-ms mask. Thus, the digits abruptly onset and offset in fairly rapid succession. Basic attention and vision research has demonstrated that abrupt onsets/offets are some of the most compelling bottom-up features of a stimulus, which can capture attention quite easily (Remington, Johnston, & Yantis, 1992; Schreij, Owens, & Theeuwes, 2008; Yantis & Jonides, 1984, 1990). When a stimulus abruptly onsets, like a flash of light or a burst of noise, it is quite difficult for our attention to avoid being captured by it, even if the stimulus is goal-irrelevant or in direct conflict with a goal (e.g., in the antisaccade task; Hallett, 1978; Hallett & Adams, 1980; Kane, Bleckley, Conway, & Engle, 2001). If an abrupt-onset stimulus can capture attention, and there is a behavior that is strongly tied to that stimulus, then SART no-go errors may be biased to occur by the abrupt onsetting and offsetting of the stimulus, rather than by inattention per se. To avoid this issue, Rosenberg, Noonan, DeGutis, and Esterman (2013) developed a novel continuous performance task in which the go/no-go probabilities remained quite similar to the SART (90% *go*, 10% *no-go* trials). This gradual-onset continuous performance task (gradCPT) still produced a large proportion of errors on *no-go* trials, and it still showed a vigilance decrement. Since this paper was published it has been used successfully in dozens of studies to investigate individual differences, age-related differences, and neural correlates of sustained attention (Fong et al., 2019; Fortenbaugh et al., 2015; Kucyi, Hove, Esterman, Hutchison, & Valera, 2017; Rosenberg et al., 2016).

Despite the supposition that abrupt- and gradual-onset make differential demands on sustained attention and/or response inhibition, at the time the present study was developed and administered, no study had directly compared abrupt- and gradual-onset sustained attention tasks like the SART and gradCPT. Therefore, the present study had two goals: 1) to test whether abrupt-onset stimuli like in the SART do indeed induce more *no-go* errors than gradually onsetting stimuli like in the gradCPT, 2) to test whether abrupt- and gradually-onsetting stimuli produce differential patterns of performance across time (i.e., vigilance decrements). Specifically, it is possible that in addition to producing more errors overall, inhibiting responses to abrupt-onset no-go stimuli taxes attention moreso than inhibiting responses to gradual-onset no-go non-targets. Alternatively, it is possible that abrupt-onset stimuli produce *shallower* vigilance decrements, than gradual-onset stimuli because the abrupt onsets continually capture and engage attention. If abrupt onsets do indeed trigger more frequent no-go errors, then we should see a larger proportion of no-go errors in conditions in which stimuli abruptly onset and offset as opposed to gradually onsetting and offsetting stimuli. If abrupt onsets also induce steeper vigilance decrements because they are harder to inhibit, we should see a steeper vigilance decrement in abrupt onset conditions compared to gradual onset conditions (negative abrupt onset x time interaction). If abrupt onsets continually capture and engage attention, then we should see shallower vigilance decrements in abrupt-onset conditions compared to gradual-onset conditions.

In addition to comparing abrupt and gradual onsets, we also manipulated stimulus exposure duration. In the canonical version of the SART, the stimuli appear briefly (~250-300 ms) followed by a blank delay (~900-1,000 ms). Participants are permitted to make a response either while the stimulus is on-screen or during the delay. In the gradCPT, a stimulus is always on-screen, and the images gradually transition from one to the next, and even overlay for brief periods of time. Thus we also compared gradual-onset conditions to abrupt-onset conditions with longer stimulus durations than is typical.

To compare conditions, we examined several dependent variables, each of which allowed us to assess the reasons for differences between conditions. First, we compared the proportion of *no-go* trial errors and their likelihood of occurrence across time. Second, we compared intraindividual variability in reaction times (RT CV), which is also often used as a measure of attentiveness. Specifically, higher RT CV is often used as a measure of inattentiveness, as this metric increases across time in both the SART and gradCPT (McVay & Kane, 2009; Rosenberg et al., 2013), and correlates with both no-go error rates within the task, tendencies to report mind-wandering, individual differences in working memory capacity, and individual differences in trait mindfulness (McVay & Kane, 2009; Rosenberg et al., 2013). This measure can also provide convergent and/or discriminant validity to the effects of abrupt/gradual onsets on no-go error rates. That is, if a comparison between conditions reveals a difference in no-go error rates but *not* in RT CV, then the differences between conditions can be attributed to the attention-capturing effect of abrupt onsets, not inattentiveness. Finally, we also examined mean RTs across conditions. Mean RTs can provide an index of overall speed of responding. It is possible that the abrupt onsets, especially in conditions with short stimulus exposure durations, push participants to respond faster, leading to more no-go errors. The goal in using these three metrics of performance was to gain a well-rounded understanding of the effects of abrupt/gradual onsets on performance in the SART/gradCPT so that any differences across conditions could be appropriately contributed to attentional capture, inattentiveness, and speed/accuracy tradeoffs. In both experiments, we manipulated stimulus-onset (abrupt vs. gradual) and stimulus duration (short vs. long) between subjects. In Experiment 1, we used digits as stimuli, similar to the SART (Robertson et al., 1997). In Experiment 2, we used images as stimuli, similar to the gradCPT (Fong et al., 2019; Fortenbaugh et al., 2015; Kucyi et al., 2017; Rosenberg et al., 2016). The analyses were similar across experiments.

Since administering the present experiments, Jun and Lee (2021) published a similar experiment in which they compared four versions of the CPT within subjects. Specifically, they compared target frequency (90% vs. 10%) and abrupt vs. gradual onsets. They found that signal discriminability was lower in conditions with a 90% compared to 10% target frequency. They also found that the vigilance decrement was steeper in the 90% compared to 10% target frequency condition. Relative to gradual onsets, abrupt onsets produced lower discriminability, and this effect was particularly strong in the 90% target frequency condition. Additionally, they observed that participants were more biased to respond in the abrupt-onset and 90% target frequency conditions. Finally, they found that discriminability in the abrupt-onset conditions correlated with preformance on an additional go/no-go task and with performance on a stop-signal reaction time task, whereas gradual-onset discriminability only correlated significantly with stop-signal reaction time. The present study was administered before this study was published. Therefore that study's results were unknown at the present study concluded. In the General Discussion, we report how the present results align with and expand on these recent findings.

Experiment 1

In Experiments 1A and 1B, participants completed one of two versions of the SART. In each experiment, the between-subjects manipulation was stimulus-onset properties (abrupt vs. gradual). Across experiments, stimulus duration varied in the abrupt-onset conditions. The gradual-onset conditions were identical across experiments. The goal was to compare how abrupt onsets affected behavioral performance indices with standard timing parameters (short stimulus duration) and modified timing parameters (long stimulus duration).

Method

Participants and procedure

The experiments were delivered online via Pavlovia.org, and the task was developed using PsychoPy (Peirce et al., 2019). Participants first read a consent form, presented as the first several screens in the task, and they gave their consent by proceeding with the experiment. After the experimental procedure, they were debriefed regarding the purpose of the study. The experimental protocol was reviewed and approved by the Institutional Review Board of the University of Texas at Arlington. Participants were randomly assigned to conditions by the program. All participants first completed a simple reaction time task during the first 30 minutes of the online session. The two tasks delivered in the session had different research aims, so the data from the simple reaction time task are not analyzed here. The design used a sequential Bayes Factor approach to determine the stopping rule for data collection (Schönbrodt & Wagenmakers, 2018a; Schönbrodt, Wagenmakers, Zehetleitner, & Perugini, 2017). Data collection stopped when the Bayes Factors for the main effect of condition and block x condition interaction were both either above 3 or below 0.33. Bayes Factors (BFs) were computed using the *BayesFactor* (Morey & Rouder, 2018) R package with default Cauchy priors, and nested linear mixed effect models were compared using the *lmBF()* function. Data collection for Experiment 1B began after the results of Experiment 1A reached these thresholds. No participants from Experiment 1A participated in Experiment 1B. The final samples included 68 participants in Experiment 1A (32 in abrupt condition, 36 in gradual condition) and 99 participants in Experiment 1B (51 in abrupt condition, 48 in gradual condition).

Task

In all conditions, participants completed 720 trials of the SART. Each trial showed a single digit (1 to 9), and participants were instructed to press the spacebar any time they saw a digit except the number 3. When they saw the number 3, they were to withhold their response. The task began with a 45-trial practice block. Then, there were 16 mini-blocks of 45 trials. For the analyses, trials were split into five blocks of 144 trials. The blocking of trials was invisible to participants - the task proceeded uninterrupted for 720 consecutive trials. Within each 45 trial mini-block, there were five *no-go* trials (i.e., 3) and 40 *go* trials (i.e., any digit other than 3). Within a mini-block the digits appeared in a random order. The order was then reshuffled for the next mini-block. In both Experiment 1A and 1B, there were two conditions: abrupt and gradual. In the abrupt condition of Experiment 1A, the digit appeared and remained on-screen for 300 ms, followed by a 900-ms blank delay screen. Participants could make their response any time within that 1,200 ms window. In the gradual condition of Experiment 1A, the digit gradually onset over the first 400 ms of the trial, remained visible for 400 ms, then gradually offset over the final 400 ms of the trial. Thus, in both cases, the trials lasted identical periods of time. Condition assignment was made by a random number generator embedded within the experimental program. Video examples of each trial sequence are included in the Supplemental Materials.

In Experiment 1A, the digits in the abrupt condition were only visible for 300 ms. In Experiment 1B, the digits in the abrupt condition were visible for 1,000 ms. To preview the results, this had a rather profound impact on performance. Rather than listing the four conditions in Experiment 1 as a 2 x 2 between-subjects design, for transparency they are reported as two sub-experiments within one experiment because they were administered in sequence. However, a combined analysis of the experiments is reported in the Results.

Data analysis

The data were analyzed in R using the *tidyverse* (Wickham, 2017), *data.table* (Dowle & Srinivasan, 2018), *lmerTest* (Kuznetsova, Brockhoff, & Christensen, 2017), and *BayesFactor* packages. The manuscript was written using the *papaja* package (Aust & Barth, 2018). Participants with hit rates below 75% were excluded. This threshold excluded 18 participants in Experiment 1A and 21 participants in Experiment 1B. Dependent variables were analyzed with linear mixed effect models, specified with block (continuous, centered at 0) and condition (sum-to-zero effects coded; abrupt = -1, gradual = 1) as fixed effects, and participant as a random effect. The intercept and effect of block were allowed to vary randomly across participants. In cases where the model did not converge upon a solution with a random effect of block for each participant, participant was included only as a random intercept (Barr, Levy, Scheepers, & Tily, 2013). Although BFs were used to estimate the weight of evidence in favor of the presence or absence of an effect, the associated t-statistics and p-values are reported, using the Satterwaithe method to estimate degrees of freedom (Kuznetsova et al., 2017). All data and analysis code are publicly available on the Open Science Framework: https://osf.io/j9gcm/

Results and Discussion

I first report the results of Experiment 1A, then Experiment 1B, then a combined analysis of the two experiments. The stopping rule for data collection in each experiment was when the BF for the block x condition interaction on no-go errors was above 3 or below 0.33. Therefore, I did not specify stopping based on the results of the comparison between Experiments 1A and 1B.

Experiment 1A

The data are plotted in Figure 1. Summaries of the linear mixed models are shown in Table 1. There was strong evidence for a main effect of block on all dependent variables, such that no-go error rates increased, hit rates decreased, mean RTs increased, and RT CV increased across blocks. There was also strong evidence in favor of a main effect of condition on no-go errors, such that no-go error rates were greater in the abrupt condition compared to the gradual condition. However, there was strong evidence against a block x condition interaction. The increase in no-go errors was not accompanied by a change in hit rates, as there was strong evidence against a main effect of condition and against a block x condition interaction on hit rates. Additionally, there was strong evidence against a main effect of condition and against a block x condition interaction on RT CV. Finally, the comparison of mean RTs revealed moderate evidence in favor of a main effect of condition but strong evidence against a block x condition interaction, such that participants in the abrupt condition tended to respond faster, overall.

Collectively, the results indicated that the abrupt-onset digits in Experiment 1A caused participants to respond faster and with greater no-go error proneness than the gradual-onset condition. In addition to committing more no-go errors, participants in the abrupt condition had faster average RTs. However, there was no difference in RT variability between conditions, nor a difference in hit rates. Therefore, the increase in no-go errors between the abrupt and gradual conditions was likely driven by a shift in the speed/accuracy tradeoff, rather than a difference in attentiveness between conditions. The abrupt onsetting and offsetting of stimuli tended to bias participants to make fast responses, which led to more errors. Experiment 1B investigated whether this was driven by stimulus duration.

Experiment 1B

The data are plotted in Figure 2, and summaries of the mixed effect models are listed in Table 2. Similar to Experiment 1A, all the dependent variables significantly changed across time: no-go error rates increased, hit rates decreased, RT CV increased, and mean RTs increased. But unlike Experiment 1A, there was evidence against a main effect of condition on no-go error rates. Furhter, with the exception of modest evidence in favor of an effect of abrupt onsets on mean RTs, there was strong evidence against main effects of condition and block x condition interactions on the other dependent variables, as well. Mean RTs were still slightly longer in the gradual condition, even with the longer stimulus duration in the abrupt-onset condition.

To specifically compare the effect of abrupt onsets across experiments, we specified models with fixed effects of condition (abrupt vs. gradual), experiment (1A vs. 1B), and their interaction as fixed effects and participant as a random effect. This comparison confirmed a difference in the effect of abrupt onsets on no-go error rates across experiments with a significant condition x experiment interaction (b = 0.042, SE = 0.013, t = 3.158, p = .002, BF_{10} = 9.49). We also compared mean RTs across conditions and experiments with an identical model. RTs were significantly longer in the gradual conditions compared to the abrupt conditions overall (b = 20.631, SE = 5.704, t = 3.617, p = < .001, BF_{10} = 21.86), and significantly longer in Experiment 1B than Experiment 1A (b = 19.358, SE = 5.704, t = 3.394, p = .001, BF_{10} = 8.86). There was not a significant condition x experiment interaction (b = -3.487, SE = 5.704, t = -0.611, p = .542, BF_{10} = 0.14).

Abrupt-onset stimuli produced significantly more no-go errors in the SART, but only when the duration of the digits was short (300 ms), as is typical (e.g., Robertson et al., 1997; Cheyne, Carriere, & Smilek, 2006; McVay & Kane, 2009, 2012; Unsworth & McMillan, 2014). When the duration of the digits was long (1,000 ms) there was no difference in no-go errors to abruptly and gradually onsetting digits. In neither experiment did RT CV differ, so it is unlikely that participants were more attentive in the gradual-onset conditions. It is more likely that the digits with abrupt onsets and offsets triggered incorrect responses because their abrupt onset and offset captured attention and induced the habitual *go* response. Overall, the results were consistent with the hypothesis that increased no-go errors in the abrupt-onset condition of Experiment 1A was due to a shift in the speed/accuracy tradeoff. The abrupt onsetting and offsetting of digits sped participants up, leading to more liberal response tendencies and more errors of no-go.

Experiment 2

The major difference between Experiment 1 and 2 was the use of images rather than digits. The task in Experiment 1 was designed to mimic typical features and trial sequences of the SART. But the gradCPT uses images that gradually transition from one to another. One category is labeled the *go* category (e.g., urban scenes) and the other category is labeled the *no-go* category (e.g., rural scenes; Rosenberg et al., 2013; Fortenbaugh et al., 2015). The tasks in Experiment 2 were thus modeled after the gradCPT. Otherwise, the experimental manipulations were largely the same. Experiments 1 and 2 were administered concurrently, so the result of Experiment 1 were not known before administering Experiment 2. In Experiment 2A, the images in the abrupt condition had a long duration (1,000 ms) and in Experiment 2B the images had a short duration (300 ms). So in that sense, the order of experiments was reversed in Experiment 2 compared to Experiment 1. However the goals were the same: 1) to determine whether abrupt onsets/offsets trigger more *no-go* errors in a go/no-go task where the trials are heavily weighted toward *go* trials, and 2) to determine whether gradual and abrupt onsets produce different patterns of performance across time (i.e., vigilance decrements). Hit rates, RT CV, and mean RT were also analyzed to attribute any potential differences to inattentiveness or speed/accuracy tradeoffs.

Method

Participants and procedure

The experiment was delivered online via Pavlovia.org, and the task was developed using PsychoPy (Peirce et al., 2019). Participants first read a consent form, and they gave their consent by proceeding with the experiment. After the experimental procedure, they were debriefed regarding the purpose of the study. The experimental protocol was reviewed and approved by the Institutional Review Board of the University of Texas at Arlington. Participants were randomly assigned to conditions by the task program. All participants first completed a simple reaction time task during the first 30 minutes of online session. The two tasks delivered in the session had different research aims, so those data are not analyzed here. We used a sequential Bayes Factor design (Schönbrodt & Wagenmakers, 2018b; Schönbrodt et al., 2017) to determine the stopping point for data collection. We stopped collecting data when all effects within an experiment achieved a Bayes Factor above 3 or below 0.33. We used default Cauchy priors from the *BayesFactor* (Morey & Rouder, 2018) R package to estimate Bayes Factors (BFs), and we compared nested linear mixed effect models using the *lmBF()* function. The data were iteratively analyzed to examine the relative magnitude for and against hypothesized effects. Data collection ceased for Experiment 1A when the Bayes Factors for the effects exceeded 3, and data collection for Experiment 2B resumed immediately thereafter. No participants from Experiment 1A participated in Experiment 2B. The final samples included 96 participants in Experiment 1A (45 in abrupt condition, 51 in gradual condition) and 67 participants in Experiment 1B (29 in abrupt condition, 38 in gradual condition).

Task

In all conditions, participants completed 720 trials of task modeled after the gradCPT. Each trial showed a grey-scaled image. Ten rural scenes and ten city scenes were selected from the SUN database of images (Xiao, Hays, Ehinger, Oliva, & Torralba, 2010). Participants were instructed to press the spacebar any time they saw a city image and withhold their response whenever they saw a rural image. Participants were first given examples of each image category. The task began with a 45-trial practice block. Then, there were 16 mini-blocks of 45 trials. For the analyses, trials were split into 5 blocks of 144 trials. The blocking of trials was invisible to participants - the task proceeded uninterrupted for 720 consecutive trials. Within each 45 trial mini-block, there were 5 *no-go* trials (i.e., rural images) and 40 *go* trials (i.e., city images). Within a mini-block the images appeared in a random order. The order was then reshuffled for the next mini-block. In both Experiment 2A and 2B, there were two conditions: abrupt and gradual. In the abrupt condition of Experiment 2A, the scene appeared and remained on-screen for 1,000 ms, followed by a 200-ms blank delay screen. In the abrupt condition of Experiment 2B, the scene appeared and remained on-screen for 300 ms, followed by a 900-ms blank delay screen. In the gradual conditions, the image gradually onset over the first 400 ms of the trial, remained visible for 400 ms, then gradually offset over the final 400 ms of the trial.[1] Thus in both cases, the trials lasted identical periods of time. Participants could make their response any time within the 1,200 ms window. Condition assignment was made by a random number generator embedded within the experimental program. The gradual conditions were identical across experiments.

[1] In the gradCPT (Rosenberg et al., 2013), the images transition over one another, and for brief periods of time they overlap. We did not include this aspect of the task in the present study. Trials were discrete, and thus responses could be unambiguously assigned to belong to the current trial.

Results and Discussion

Experiment 2A

The data are plotted in Figure 3, and the models are summarized in Table 3. There was strong evidence for a main effect of block on all dependent variables, such that *no-go* error rates increased, hit rates decreased, mean RTs increased, and RT CV increased across blocks. There was strong evidence against a main effect of abrupt onsets on no-go error rates, hit rates, and RT CV. However there was strong evidence in favor of an effect of abrupt onsets on mean RTs, such that participants responded faster in the abrupt condition. There was also strong evidence against block x condition interactions on *no-go* error rates, hit rates, and RT CV. There was modest evidence in favor of a block x condition interaction on mean RTs (steeper increase in gradual condition across blocks). But collectively, the results indicated that the abrupt onset condition did not systematically alter the tendency to commit *no-go* errors or alter attentiveness, as indexed by RT CV. These results complement what was observed in Experiment 1B with long-duration digit stimuli.

Experiment 2B

The data are plotted in Figure 4, and the models on each dependent variable are summarized in Table 4. There was strong evidence of an effect of block on all dependent variables, such that *no-go* error rates increased, hit rates decreased, mean RTs increased, and RT CV increased across blocks. There was also strong evidence in favor of a main effect of condition on *no-go* errors, such that participants in the abrupt condition committed more errors than participants in the gradual condition. There was also strong evidence in favor of a block x condition interaction on *no-go* errors, but the gradual condition actually showed a steeper increase in *no-go* errors across blocks than the abrupt condition. Interestingly, hit rates were significantly *lower* in the abrupt condition. This is an effect that was not observed in Experiment 1A. Thus, it appears that in addition to speeding up, the abrupt-onsetting image stimuli with short durations also made it difficult for participants to distinguish between target and non-target scenes. Perhaps, the short exposure duration made it more difficult for participants to decipher between the rural and urban scenes, especially if they were not paying careful attention. Similar to Experiment 1, mean RTs were also faster in the abrupt condition. But unlike Experiment 1 and Experiment 2A, there was a significant increase in RT CV in the abrupt condition, and there was modest evidence for a block x condition interaction, such that participants in the abrupt condition showed a steeper increase in RT CV across blocks. Thus, the short-duration abrupt-onset condition was the only condition in which participants seemed less attentive overall than participants in the gradual-onset condition.

Overall, the results of Experiment 2A were consistent with those of Experiment 1B. When stimuli remained on-screen for a relatively long time, even if they abruptly onset and offset, patterns of performance were largely the same as gradual-onset conditions. The only effect that arose comparing long-duration abrupt conditions to gradual conditions was a decrease in mean RTs in the abrupt conditions. The short-duration, abrupt-onset images in Experiment 2B replicated some patterns from Experiment 1A, but produced several new effects. In both Experiment 1A and 2B, the short-duration abrupt-onset stimuli led to more *no-go* errors and faster RTs, but only images also induced more RT variability and lower hit rates. Potentially, this is because images are a bit harder to categorize than single digits, and thus the short durations reduced overall discriminability (as indexed by higher false alarms and lower hit rates) and made the task harder to maintain focus on (as indexed by higher RT variability).

General Discussion

The goal of the present study was to test whether gradual- and abrupt-onset continuous performance go/no-go tasks produce systematically different patterns of performance. This was accomplished by comparing conditions with abrupt- or gradual-onset stimuli across two stimulus durations and two stimulus types. We analyzed *no-go* error rates (incorrectly emitted responses on *no-go* trials), hit rates (correct responses on *go* trials), average RTs on *go* trials, and intraindividual RT variability on *go* trials. The two experiments revealed largely overlapping patterns of results. There were several consistent findings, which we interpret below.

First, gradual- and abrupt-onset stimuli only affected performance when the abrupt-onset stimuli had a short duration. The only performance metric that still differed between gradual-onset and long-duration abrupt-onset conditions was mean RTs. Participants still responded slower, overall, when the stimuli gradually onset compared to when they abruptly onset. This pattern was consistent regardless of stimulus type (digit or image). Second, short-duration abrupt-onset stimuli induced more *no-go* errors for both images and digits. However, this seemed to be indicative of greater inattentiveness only when the stimuli were images. In Experiment 1A, when the stimuli were digits, participants in the abrupt-onset condition committed more *no-go* errors and had faster RTs, but they did not show more RT variability, nor did they have lower hit rates. Rather, the effects seemed to be driven by a shift toward speed in the speed/accuracy tradeoff. In other words, participants were biased toward fast responding, which led to more error proneness. In Experiment 2B, this pattern was slightly different. Participants in the abrupt-onset condition had higher *no-go* error rates and faster RTs, but they also had lower hit rates and more RT variability. Therefore, this condition seemed to produce qualitatively different attentiveness than the other abrupt-onset conditions. Possibly, the short-duration images were more difficult to decipher compared to short-duration digits, making the task more difficult overall and producing lower performance metrics across the board. Finally, the short-duration abrupt-onset condition with images (Experiment 2B) was the only condition to show differential patterns of performance across time (i.e., vigilance decrements) compared to gradual-onset conditions. In 3 of the 4 abrupt-onset conditions (short-duration digits, long-duration digits, and long-duration images), participants did not not show steeper vigilance decrements, in either *no-go* error rates or RT CV, compared to gradual-onset conditions. So by and large, it not appear that the inhibition of abrupt onsets differentially taxed nor engaged sustained attention in a way that produced systematically different vigilance decrements.

The present results complement those recently reported by Jun and Lee (2021). In that study they used one similar experimental manipulation (abrupt vs. gradual onsets) and one different manipulation (target frequency: 10% vs. 90%). All four conditions in the study used images as stimuli (city vs. mountain scenes). In their abrupt-onset conditions, the stimuli appeared and remained on-screen for 560 ms, separated by a 240-ms blank delay. In the gradual-onset conditions, the stimuli gradually transitioned from one to the next every 800 ms. So the stimulus duration in the abrupt conditions was right in between the durations we used in Experiment 2. But overall, trials were shorter in duration. Some of the present results are consistent with those of Jun and Lee (2021). Specifically, Jun and Lee (2021) observed significantly lower stimulus discriminability and significantly faster RTs in the abrupt-onset conditions compared to gradual-onset conditions. This is consistent with what was observed in the present study, but only in the short-duration abrupt-onset conditions (Experiments 1A and 2B). At longer durations (Experiments 1B and 2A), there were no differences in stimulus discriminability. Thus, the combination of the shorter trial duration and shorter stimulus durations in the abrupt-onset conditions Jun and Lee (2021) led to similar to patterns of performance as the present study. However, the present study adds to these findings by showing that at longer stimulus durations, and longer trial durations, these effects go away.

Implications

The present results have implications for at least three areas of research: experimental investigations, individual/developmental differences investigations, and psychophysiological/neuroscientific investigations of sustained attention. In any field, it is important to give careful consideration to the psychometrics of any given measure, whether it be a cognitive task, a clinical screening questionnaire, or a social simulation. From the present findings, we can form several conclusions. First, short-duration, abrupt-onset stimuli produce significantly more *no-go* errors than gradual-onset stimuli, both digits and images. However, this effect was not present for long-duration stimuli. Therefore, we cannot be certain that *no-go* error rates in gradual and abrupt-onset *go*/*no-go* tasks, as a dependent variable in an experimental design, as an individual/developmental difference, or as a behavioral correlate of a neural/psychophysiological metric are isomorphic. It does indeed appear that there is an element of attentional capture to the abruptness of stimuli in tasks like the SART, which induces greater *no-go* errors. Therefore, tasks like the SART measure at least three cognitive processes: 1) the ability to override an automatic response on rare *no-go* trials, 2) the ability to sustain attention to the task so as to avoid a worsening of performance across time, and 3) the ability to resist attentional capture by an abrupt-onset stimulus. Gradual-onset tasks, like the gradCPT, perhaps only measure two of these three abilities, with the attentional capture effect removed. So this begs the question, which task is "best"? Well, as with most things, the answer is probably, "it depends." The fact that short-duration, abrupt-onset stimuli produce greater *no-go* error rates can be either advantageous or disadvantageous, depending on the researcher's goals. If the goal is to provide participants with a task that places maximal demands on the ability to inhibit strong prepotent response tendencies, abrupt-onset, short-duration stimuli may be best. If the goal is to remove the confounding influence of attentional capture on goal maintenance/inhibition of prepotent responding, gradual-onset tasks may be best. If the researcher wants to avoid gradual-onset tasks so that stimuli are static and discretely presented in sequence, but wants to avoid the effects of attentional capture, abrupt-onset, long-duration stimuli may be best. The answer to *which task is best?* depends on the researcher's goals.

In future work, experimental manipulations like those used in the present study and those used by Jun and Lee (2021) should be combined with simultaneous measurement of other individual differences, developmental differences, and neural/psychophysiological recordings. For example, it has been demonstrated that both RT CV and *no-go* error rates from the SART can be used as measures of attention control in individual differences investigations (Cheyne et al., 2006; Kane et al., 2016; McVay & Kane, 2009, 2012; Unsworth & McMillan, 2014; Unsworth, Robison, & Miller, 2021), and it has been demonstrated that individual differences in performance in the gradCPT can be correlated with neural measures of whole-brain functional connectivity (Rosenberg et al., 2016). What is needed in future research is an assessment of how gradual- and abrupt-onset *go/no-go* tasks tap into similar or unique individual differences. Jun and Lee (2021) correlated performance in the gradual- and abrupt-CPT with external tasks, but their sample only included 43 participants. Future work should examine performance metrics on gradual- and abrupt-onset tasks with large sample sizes that can reliably and precisely estimate correlations (Schönbrodt & Perugini, 2013). Additionally, performance on these tasks should be correlated with external tasks, like the method used by Jun and Lee (2021), to examine which task best correlates with other measure of attention control, response inhibition, and/or sustained attention in latent variable analyses of these abilities.

From a developmental perspective, studies using abrupt- and gradual-onset tasks may produce different patterns of results when comparing performance in younger and older participants. Both tasks have been used to examine age-related change in sustained attention. For example, Fortenbaugh et al. (2015) examined performance on the gradCPT in a large sample of participants aged 10 to 70. They found that performance metrics and strategic approaches both shifted over three developmental windows - from childhood to late adolescence, from late adolescence into middle age, and from middle age to late adulthood. Specifically, RT variability decreased across adolescence (age 10 - 16), then stabilized and was lowest during adulthood (age 16 - 44), then began to increase again as people reached late adulthood (age 45 - 70). Similarly, discriminability rapidly increased across adolescence, increased more slowly and reached its peak in middle age, then decreased again during late adulthood. Interestingly, strategic approaches showed a rather monotonic change across adulthood. Specifically, older participants shifted to a more conservative response strategy, favoring accuracy over speed, and also showed more post-error slowing across adulthood. Along similar lines, Vallesi, Tronelli, Lomi, and Pezzetta (2021) recently published a meta-analysis of age-related performance differences in the SART. Compared to younger adults, older adults exhibit fewer *no-go* errors but longer average *go* trial RTs. Both studies observed shifts in the speed/accuracy tradeoff toward accuracy in older adults. Future work should examine the abrupt- and gradual-onset tasks simultaneously in both age groups to see how the groups differ in sustained attention, response inhibition, and/or speed/accuracy strategies. Perhaps, the different demands made by abrupt-onset tasks and gradual-onset tasks will allow for a better parsing of age-related changes in cognition, independent of age-related changes in response stategies.

Finally, the present results indicate a path for future differentiation of abrupt- and gradual-onset tasks and their physiological correlates. For example, if the abrupt- and gradual-onset tasks make differential demands on the brain systems that implement sustained attention and response inhibition, respectively, then different patterns of neural activity should be observed when completing these two types of tasks. Further, gradual-onset tasks might be preferable in designs that use a physiological tool like EEG or pupillometry, as they should elicit smaller visually-evoked responses caused by the abrupt onsetting and offsetting of stimuli. However, a careful comparison of these tasks using such tools has not been completed, and is necessary.

Conclusions

Abrupt-onset sustained attention tasks, like the SART, produce significantly more errors on *no-go* trials than gradual-onset tasks when the stimuli have brief exposure durations (~300 ms), as is typical. This effect is also modulated by whether digits or images are used as the choice stimuli. With short-exposure digits, participants show a shift in the speed/accuracy tradeoff toward speed. With short-exposure scenes, participants emit more errors, fewer correct responses, faster RTs, and more RT variability. At longer stimulus durations, the only difference between abrupt- and gradual-onset tasks was a speeding of RTs in abrupt-onset conditions, regardless of stimulus type. In future work, abrupt-onset gradual-onset tasks should be compared when investigating individual differences, developmental differences, and neural correlates of sustained attention and response inhibition.

Open Practices Statement

As a step to ensure the replicability and transparency of the present study, all data and analysis code are publicly available on the Open Science Framework (https://osf.io/j9gcm/). Any questions or concerns can be directed to the author at the email address listed in the Author Information section.

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Table 1

Summary of models on dependent variables in Experiment 1A

DV	Effect	*b*	*SE*	*t*	*p*	BF_{10}
No-go error rate	Intercept	0.510	0.020	25.597	< .001	—
	Block	0.043	0.006	6.643	< .001	> 100,000
	Condition	-0.081	0.020	-4.072	< .001	98.76
	Block x condition	0.006	0.006	0.962	.339	0.13
Hit rate	Intercept	0.958	0.006	171.714	< .001	—
	Block	-0.013	0.003	-5.147	< .001	> 100,000
	Condition	0.009	0.006	1.631	.108	0.30
	Block x condition	0.001	0.003	0.547	.586	0.24
Mean RT	Intercept	392.475	9.724	40.360	< .001	—
	Block	8.658	3.040	2.848	.006	> 100,000
	Condition	24.195	9.724	2.488	.015	2.59
	Block x condition	-0.494	3.040	-0.163	.871	0.03
RT CV	Intercept	0.415	0.018	22.701	< .001	—
	Block	0.043	0.005	8.294	< .001	> 100,000
	Condition	0.006	0.018	0.348	.729	0.31
	Block x condition	0.004	0.005	0.705	.483	0.18

Note. *DV* = dependent variable, *b* = regression estimate, *SE* = standard error of regression estimate, BF_{10} = ratio of evidence (Bayes Factor) in favor of effect.

Table 2

Summary of models on dependent variables in Experiment 1B

DV	Effect	*b*	*SE*	*t*	*p*	BF_{10}
No-go error rate	Intercept	0.408	0.017	23.423	$< .001$	—
	Block	0.039	0.005	8.558	$< .001$	$> 100{,}000$
	Condition	0.004	0.017	0.211	.833	0.13
	Block x condition	-0.001	0.005	-0.234	.816	0.05
Hit rate	Intercept	0.949	0.006	146.997	$< .001$	—
	Block	-0.017	0.001	-29.184	$< .001$	$> 100{,}000$
	Condition	0.000	0.006	0.031	.975	0.11
	Block x condition	0.001	0.001	1.802	.072	0.03
Mean RT	Intercept	431.419	6.817	63.285	$< .001$	—
	Block	9.791	2.454	3.990	$< .001$	$> 100{,}000$
	Condition	17.027	6.817	2.498	.014	1.98
	Block x condition	-1.141	2.454	-0.465	.643	0.08
RT CV	Intercept	0.398	0.013	30.626	$< .001$	—
	Block	0.036	0.004	8.719	$< .001$	$> 100{,}000$
	Condition	-0.002	0.013	-0.124	.901	0.26
	Block x condition	0.004	0.004	0.858	.393	0.14

Note. DV = dependent variable, b = regression estimate, SE = standard error of regression estimate, BF_{10} = ratio of evidence (Bayes Factor) in favor of effect.

Table 3

Summary of models in Experiment 2A

DV	Effect	b	SE	t	p	BF_{10}
No-go error rate	Intercept	0.359	0.017	20.671	$< .001$	—
	Block	0.007	0.001	6.453	$< .001$	$>$ 100,000
	Condition	-0.011	0.017	-0.624	.534	0.13
	Block x condition	0.002	0.001	1.555	.120	0.14
Hit rate	Intercept	0.988	0.0059	168.079	$< .001$	—
	Block	-0.006	0.0002	-33.828	$< .001$	$>$ 100,000
	Condition	-0.004	0.0059	-0.628	.531	0.11
	Block x condition	0.001	0.0002	3.726	$< .001$	0.02
Mean RT	Intercept	477.603	7.160	66.705	$< .001$	—
	Block	7.136	2.059	3.466	.001	$>$ 100,000
	Condition	36.478	7.160	5.095	$< .001$	3,104.31
	Block x condition	0.798	2.059	0.388	.699	2.50
RT CV	Intercept	0.337	0.010	33.359	$< .001$	—
	Block	0.028	0.003	9.844	$< .001$	$>$ 100,000
	Condition	-0.012	0.010	-1.158	.250	0.45
	Block x condition	-0.002	0.003	-0.634	.527	0.12

Note. DV = dependent variable, b = regression estimate, SE = standard error of regression estimate, BF_{10} = ratio of evidence (Bayes Factor) in favor of effect.

Table 4

Summary of models in Experiment 2B

DV	Effect	*b*	*SE*	*t*	*p*	BF_{10}
No-go error rate	Intercept	0.498	0.024	21.004	$< .001$	—
	Block	0.005	0.001	3.658	$< .001$	330.03
	Condition	-0.158	0.024	-6.658	$< .001$	2,431.23
	Block x condition	0.007	0.001	5.508	$< .001$	6,720.15
Hit rate	Intercept	0.971	0.0081	119.511	$< .001$	—
	Block	-0.005	0.0002	-21.157	$< .001$	$>$ 100,000
	Condition	0.004	0.0081	0.544	.588	2.85
	Block x condition	0.003	0.0002	12.090	$< .001$	$>$ 100,000
Mean RT	Intercept	450.283	10.394	43.323	$< .001$	—
	Block	8.640	3.408	2.535	.014	$>$ 100,000
	Condition	46.107	10.394	4.436	$< .001$	461.71
	Block x condition	-3.498	3.408	-1.026	.308	$>$ 100,000
RT CV	Intercept	0.367	0.016	23.259	$< .001$	—
	Block	0.029	0.005	6.317	$< .001$	$>$ 100,000
	Condition	-0.058	0.016	-3.678	$< .001$	25.99
	Block x condition	-0.006	0.005	-1.196	.236	2.64

Note. *DV* = dependent variable, *b* = regression estimate, *SE* = standard error of regression estimate, BF_{10} = ratio of evidence (Bayes Factor) in favor of effect.

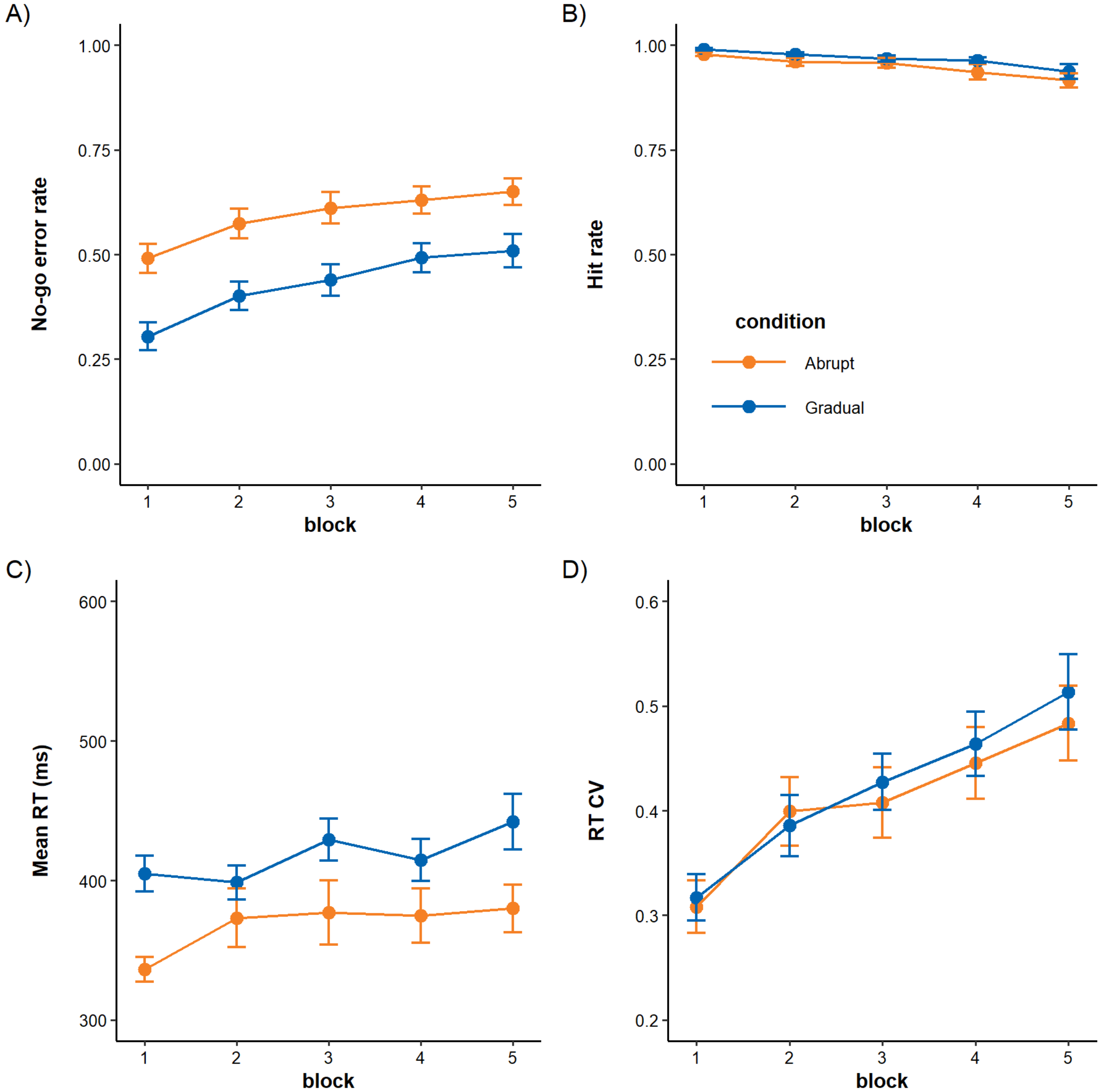

Figure 1. A) No-go error rates, B) Hit rates, C) Mean reaction times (RTs), and D) Reaction time variability (RT CV) by block and condition in Experiment 1A. Error bars represent +/- one standard error around the mean.

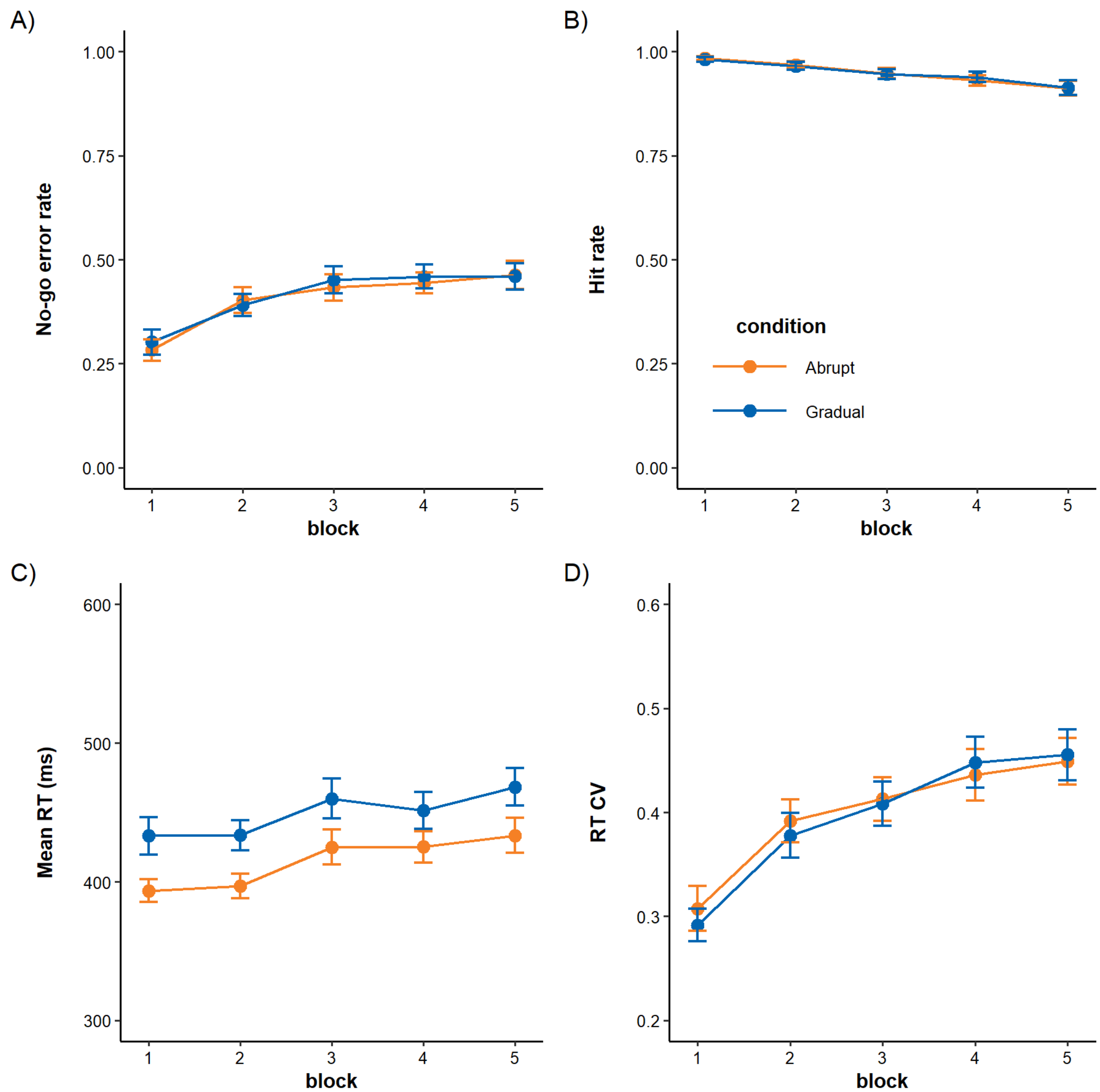

Figure 2. A) No-go error rates, B) Hit rates, C) Mean reaction times (RTs), and D) Reaction time variability (RT CV) by block and condition in Experiment 1B. Error bars represent +/- one standard error around the mean.

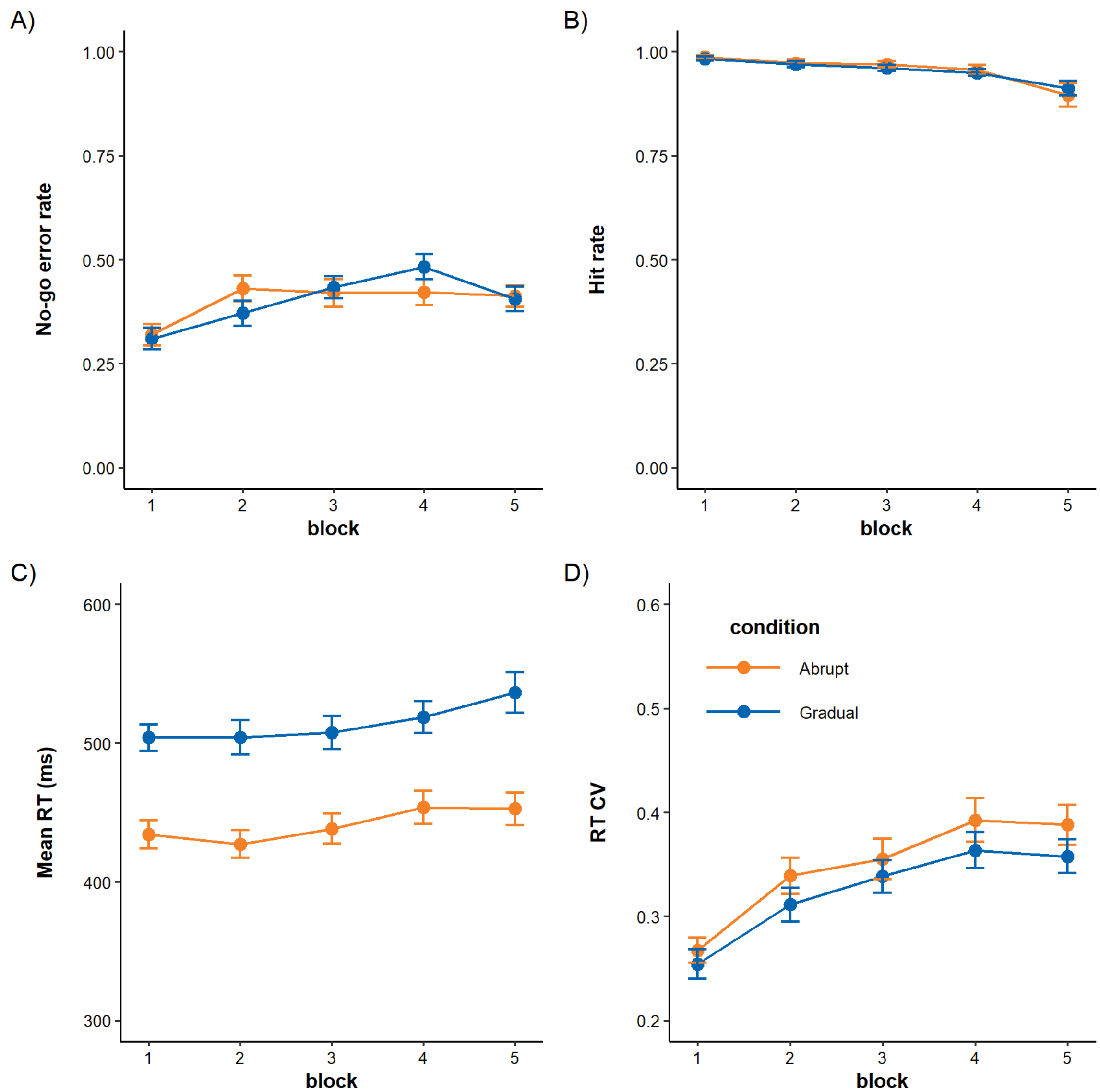

Figure 3. A) No-go error rates, B) Hit rates, C) Mean reaction times, and D) Reaction time variability (RT CV) by block and condition in Experiment 2A. Error bars represent +/- one standard error around the mean.

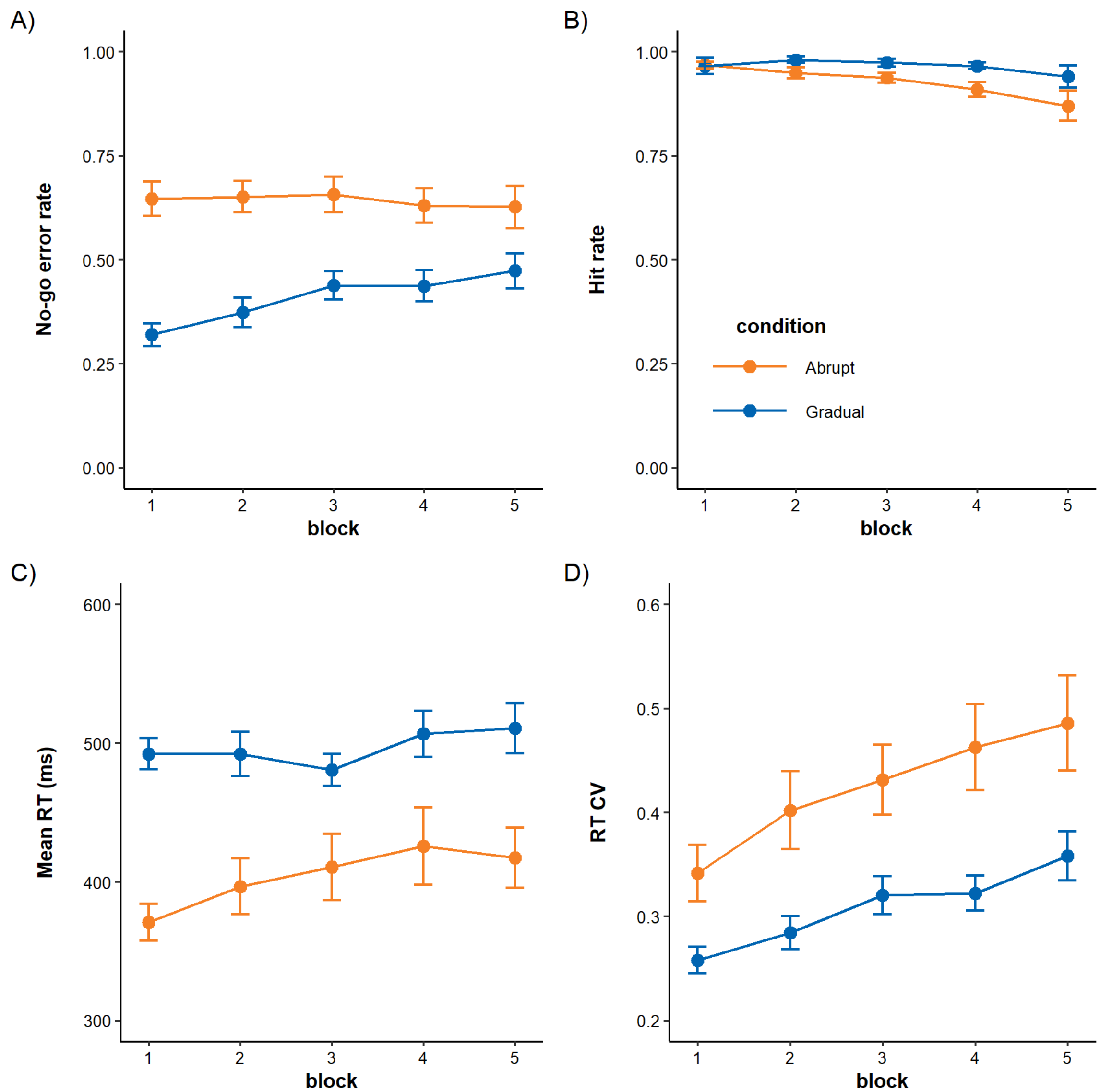

Figure 4. A) No-go error rates, B) Hit rates, C) Mean reaction times, and D) Reaction time variability (RT CV) by block and condition in Experiment 2B. Error bars represent +/- one standard error around the mean.