PUPILLARY CORRELATES OF SUSTAINED ATTENTION DURING ATTEMPTS TO MOBILIZE EFFORT

by

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The present study aimed to examine the extent to which individuals were capable of mobilizing more effort to enhance task performance and how this mobilization was demonstrated through the pupillary response. Participants (*N*=82) from the University of Oregon completed a 30-minute psychomotor vigilance task in which they were presented with a row of 0s on the screen and asked to press the spacebar as soon as the numbers began to change in value. Participants were randomly assigned to the Control condition or the Try Hard condition which had an instruction to 'try hard' prior to certain trials. Results suggested that those in the Try Hard condition had improved performance (faster RTs, less off-task behavior, less lapses in attention) and a larger pupil size, thus demonstrating that individuals are in fact able to increase effort levels when encouraged to do so. For participants within the Try Hard condition, there was no significant difference in performance or pupillary response based on trial type. This implies that similar levels of effort were applied in this condition whether or not the 'try hard' instruction was presented.

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Introduction

Momentary disengagement from tasks at hand occurs daily and can result in consequences of varying magnitude. Disengagement from a task is known as a lapse in attention, which everyone has experienced to some degree at one point or another. For instance, driving through a stop light intersection and afterwards being unsure whether or not the light was actually green. Other lapses in attention, however, can have massive detrimental effects. Consider, for example, a plane pilot rapidly descending in the air during a lapse. Given the pervasive and consequential nature of attentional lapses, the present study was largely concerned with testing the following notion: Can encouraging individuals to mobilize more effort with instructions to ‘try hard’ prevent additional lapses, resulting in better task performance?

Research has been conducted to better understand how attention processes during tasks and lapses in attention relate to pupillary responses (Alnaes, Sneve, Espeseth, Endestad, Van de Pavert & Laeng, 2014; Beatty & Lucero-Wagoner, 2000; Unsworth, Robison & Miller, 2018), as well as the ability of individuals to consciously increase their effort levels, (Kleinsorge, 2001; Steinborn, Langner & Huestegge, 2017), though these two ideas have not yet been researched in unison; hence, the main purpose of this study. The present study examines the relation between effort mobilization (changing of effort levels) and changes in task performance by utilizing pupillary responses as an online indicator of the amount of attentional effort an individual devotes to a task. Specifically, this study will explore changes in pupil dilation in response to instructing participants to try harder on certain trials compared to Standard trials. Results of this study will help to further the understanding of how individuals can increase the amount of effort devoted to a task and if this is connected to improved performance. Furthermore, after additional extended research, this study has the potential to contribute to the future development of technology, such as one that provides a stimulus to individuals encouraging them to increase their attention to potentially help prevent accidents caused by lapses in attention.

Background

The Locus Coeruleus Norepinephrine System and Pupil Diameter

The capacity of an individual to complete a task to the best of their abilities is primarily dependent upon their attention levels; arousal is an imperative factor influencing the strength of attention and thus, the ability of individuals to focus on a task. Arousal levels are influenced by the locus coeruleus norepinephrine (LC-NE or LC) system, (Lenartowicz, Simpson & Cohen, 2013), a brainstem modulatory nucleus with extensive reach throughout the brain that controls the majority of norepinephrine (NE) release (Unsworth & Robison, 2018). NE is the neurotransmitter—a chemical substance that transmits information in the body—most heavily involved in the control of attention.

The LC-NE system is vital to understanding how attention levels fluctuate and, consequently, the causes of poor performance. It has been found that when the LC system is activated, there is an elevated level of alertness due to the activation of norepinephrine receptors (Samuels & Szabadi, 2008). Innervation of NE receptors leads to a generalized increase in cortical activity due to the increased levels of norepinephrine in the brain; high levels of NE thereby contribute to higher levels of alertness (Samuels & Szabadi, 2008). Fluctuations in alertness are responsible for decreased performance in sustained attention tasks (Smith & Nutt, 1996), typically demonstrated by longer reaction times or a lack of reaction (i.e., an omission error). Attentional processing is primarily controlled by the parietal and prefrontal cortex regions of the brain. Norepinephrine activation in the prefrontal cortex of rats resulted in increased performance which was thought to be a result of increased arousal levels (Samuels & Szabadi, 2008). In a study conducted by Smith et al. (1996), low NE levels were actually associated with a greater number of attentional lapses, thus highlighting the importance of high NE levels for maintaining attention.

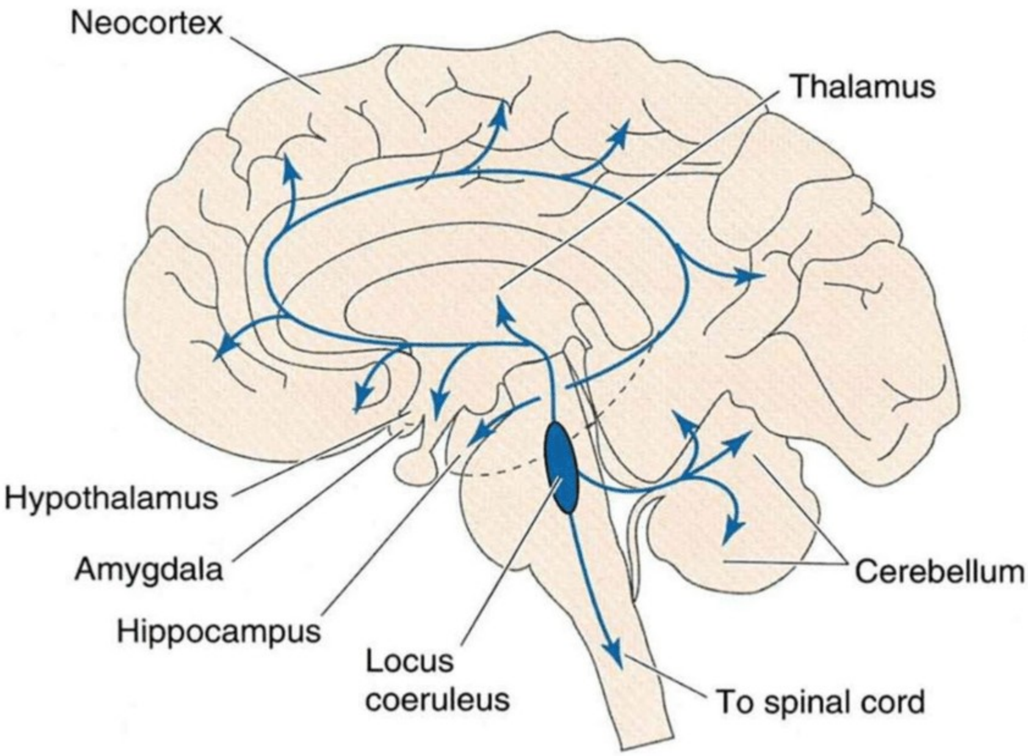


Figure 1. Locus coeruleus location and the areas of the brain it impacts (Lin & Vartanian, 2018)

Attention is also extensively controlled by the fronto-parietal network (FPN) of the brain. This network gets recruited when there are multiple competing sensory signals and also contributes to the suppression of distractions (Lenartowicz et al., 2013). The FPN and LC-NE system are linked through synapses—electrical impulses for communication. Therefore, sustained attention relies on the functioning of the LC-NE system, such that deviations in the LC-NE can result in variations in arousal and, consequently, fluctuations in attention levels.

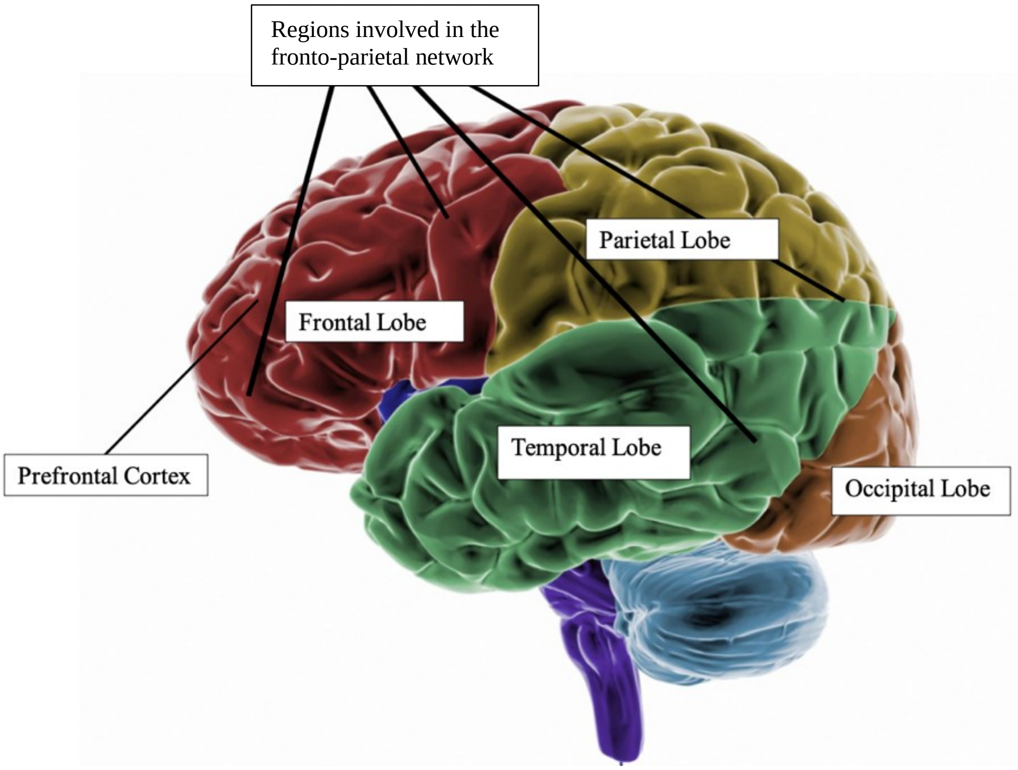


Figure 2. Areas of the brain involved in the fronto-parietal network (Bailey, 2019)

The LC-NE system has two firing modes: tonic (baseline) and phasic (changes in firing in response to a stimulus). Tonic LC activity is associated with disengagement from the task, whereas phasic LC activity is associated with task-related decisions and optimization of performance (see Figure 3) (Aston-Jones & Cohen, 2005). When tonic LC activity is low (hypoactive), the alertness and attention of the individual is also low, making them more prone to facing a lapse in attention. As tonic LC activity increases to intermediate levels (phasic), the individual experiences increased attention and alertness, thereby improving their performance on the task (Unsworth et al., 2018). If tonic LC activity increases beyond a certain point, however, the individual becomes hyperactive and is in a more easily distractible state, again making them more prone to lapses in attention (Gilzenrat, Nieuwenhuis, Jepma, & Cohen, 2010) and poorer performance. This highlights a general, ideal range for LC-NE firing levels in order to maximize attention levels for optimal performance.

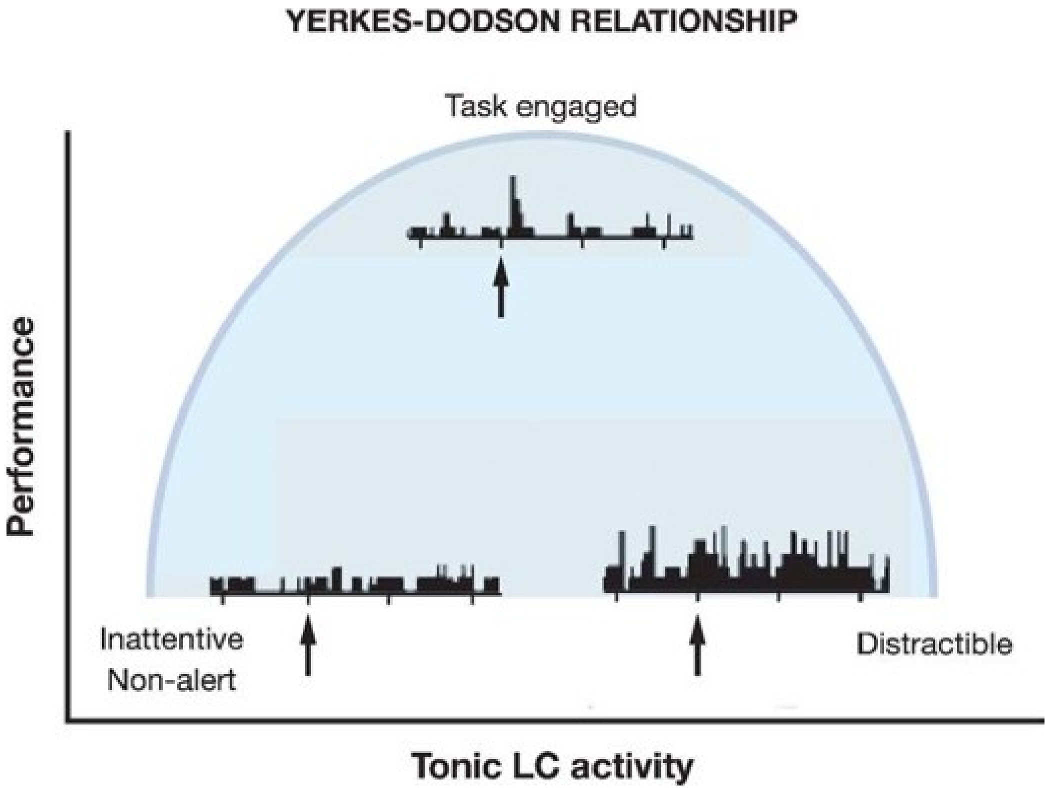


Figure 3. Variations in attention levels, and therefore performance, due to tonic and phasic LC firing (Aston-Jones & Cohen, 2005)

A well-established method of examining changes in attention allocation is through pupillometry (the measure of pupil size). Prior research has revealed that the pupil increases in size in response to cognitive demand. These changes in pupil dilation relative to baseline levels are known as Task-Evoked Pupillary Responses (TEPRs), which correspond to the intensive aspect of attention insofar that the pupil will dilate in response to the task and the amount of effort required (Beatty & Lucero-Wagoner, 2000). For example, Hess and Polt (1964) had participants complete a series of tasks involving mentally calculating the product of two numbers with each trial varying in the difficulty level of the calculation. They found that the participants' pupils dilated while they mentally calculated the answer and that the extent of dilation varied in relation to the difficulty of the calculation. Other research has further shown pupillary dilation as a response to increasing memory load in short-term memory tasks (Kahneman & Beatty, 1966). These results imply that dilation of the pupil can be reflective of increased attentional effort allocation. In a study conducted by Alnaes and colleagues (2014), while examining the relationship between pupillary response and the LC system through fMRI (functional magnetic resonance imaging), it was critically found that not only did the pupil dilate in response to the number of objects participants had to track for the task, but this increase in mental effort was further supported by an increase in LC-NE activity shown through fMRI. This was the first study to directly correlate an increase in mental load with pupillary dilation and increased activation of the LC-NE.

Lapses in Attention

Understanding the basis for why lapses in attention occur relies on recognizing factors that distract individuals from the task at hand and how this is connected to pupillary fluctuations. Sustained attention is heavily influenced by levels of motivation, arousal, and alertness (Lenartowicz et al., 2013; Samuels & Szabadi, 2008). Extreme fluctuations in these levels result in lapses in attention, in which the individual disengages from the task. Lapses in attention can arise in the form of mind-wandering (i.e., thoughts unrelated to the task at hand/daydreaming), mind-blanking (i.e., episodes of zoning out/absence of thought) or by external distraction (having one’s attention oriented away from the task due to external sources, such as hunger or loud sounds in the environment) (Unsworth & Robison, 2016).

One method of examining these fluctuations in attention is to simply ask participants what they are thinking about during the task via the thought-probe technique. Specifically, participants are periodically probed and are asked to report whether their attention was currently on-task or whether they were off-task (e.g., mind-wandering, mind-blanking, or externally distracted). Studies have even used thought probes while monitoring pupillary responses. For instance, Unsworth and Robison (2016) found that when participants indicated they had experienced mind-wandering, they had a smaller tonic pupil diameter, worse performance, and smaller TEPRs. Additionally, when participants indicated they were on-task, they had faster response times, larger TEPRs and a larger baseline (tonic) pupil diameter. The implications of this study demonstrate that when a participant experiences mind-wandering, they are experiencing a general lapse in attention, illustrated by their worse performance and smaller pupil size.

Another means of assessing attentional lapses is to examine processes that occur when participants have exceptionally slow reaction times. Additional work by Unsworth et al. (2018) suggests that processes occurring before these slow responses are important. That is, pre-trial pupil diameter is important for tracking lapses in attention. Specifically, Unsworth and colleagues demonstrated that the slowest response times (indicative of lapses in attention) in a psychomotor vigilance task were associated with no changes in pupil dilation during the ISI (the wait time before stimuli is presented, before a response is required). Conversely, the fastest responses were associated with a large increase in pupil dilation before the onset of the stimulus (i.e., the end of the ISI period). This reflects an enhanced preparatory response when participants are on-task, such that on-task trials are associated with a ramp up in attentional effort (as shown via pupil dilation) prior to stimulus onset. Taken altogether, the results reviewed above suggest attentional lapses, whether assessed via thought probes or the slowest reaction times, are related to smaller pupillary responses before and after stimuli onset.

Effort Mobilization

Research has begun to develop an understanding of how and if individuals can increase their effort levels and the effect this has on their performance. As mentioned earlier, lapses are associated with changes in the tonic and phasic levels of the LC-NE system, and existing literature has found that when an individual experiences a lapse in attention, they have poorer performance as well as a smaller pupillary response. To better understand if these lapses can be prevented, new research has begun to examine the ability of individuals to consciously increase their effort levels. These studies have found that when individuals were presented with instructions to increase effort, they were able to enhance their performance on the task, as humans have a reserve of effort that can be mobilized when required (Steinborn et al., 2017). However, this area of research has only examined the effect of instructions to try harder on performance and it has yet to be thoroughly examined how exactly performance is enhanced under such conditions and whether this improved performance corresponds to changes in pupil dilation. It seems possible that instructions encouraging participants to try harder enhances performance by increasing the amount of attentional effort devoted to the trial (reflected in larger pupillary responses) and by encouraging more on-task thought. The present study sought to address these possibilities.

Steinborn et al. (2017) conducted a study aimed to better understand the extent to which effort levels can be increased when completing a task. This was done by looking at if participants were able to improve their performance when instructed to try harder and how the waiting period before presentation of the task influenced their performance. Participants were told to respond as quickly and accurately as possible on the task and that occasionally they will be presented with an instruction to try harder prior to the ISI of that trial. The study found that this explicit instruction did improve the processing speed while the error rate did not significantly change. This demonstrates that individuals are capable of increasing how much effort they devote to a task especially when given instruction to do so.

Another study by Kleinsorge (2001) examined a similar concept by attempting to better understand if increased mobilization of effort occurred with a trade off in error rate. That is, if participants are asked to respond faster, is it because they are trying harder or is it because they are attempting to respond faster without regard for accuracy? They also looked at how the time of the pre-cuing interval, PCI, (amount of time given between the instruction to speed up response time and presentation of the task) influenced response time. Participants completed two experiments, both of which suggested that they were able to increase effort levels when asked to do so and generally, the extent of increased effort depended on the PCI length. The results of this study suggested that instructions to respond faster did, in fact, promote faster responses, specifically with shorter PCIs, though in the first experiment, this was complemented with an increase in error rate when the PCI length was short.

The Present Study

The existing literature has formed a foundation for this study by demonstrating that as individuals increase their attention, their pupil dilates, and they have better performance on tasks. Inversely, when individuals have worse performance, it is highly probable that they have faced a lapse in attention, indicated by a smaller pupil size and exceptionally slow reaction times. Additionally, individuals have the capability of increasing their effort levels on a task, especially when prompted to do so. However, the combination of these two areas of research has yet to be examined—specifically, if prompting individuals to try harder on tasks will prevent a lapse in attention (evident through improved performance) and how this is depicted through pupil size. This study will take the existing literature one step further by examining changes in the pupillary response both before and after the onset of the task stimulus.

As it has been established that better performance is associated with dilated pupils and that instructions to increase effort are associated with improved performance, we predicted that individuals would be able to increase their effort levels when instructed to ‘try hard’ which should be reflected by a dilated pupillary response. That is, when told to increase effort, individuals should increase attention on those trials, resulting in a more dilated pupil prior to the stimulus and once the stimulus appears onscreen. Presumably, these ‘try hard’ trials should also be associated with better performance (faster RTs) and less attentional lapses (indexed with thought probes). To examine these possibilities, participants completed a standard sustained attention task, the psychomotor vigilance task, while pupil diameter was simultaneously assessed.

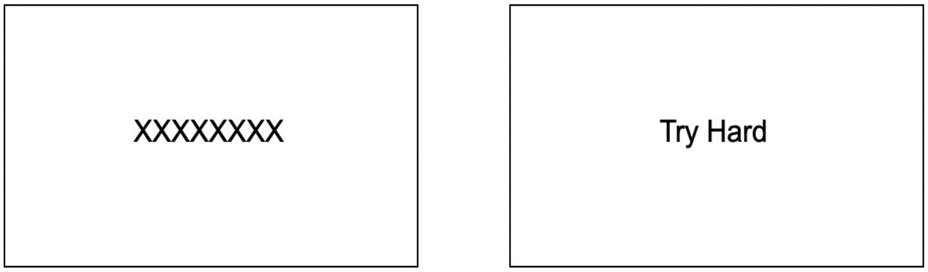
Methods

Participants

Participants (N=82) were individuals between the ages of 18 and 35 recruited from the Human Subject Pool at the University of Oregon. Each participant was tested individually in a laboratory session lasting approximately 120 minutes total. Note that the task reported herein was part of a larger experimental session. As the other tasks administered were unrelated to the present study, they are not reported but instead were used as a control; the task specific to this study was the last task in this sequence and lasted 30 minutes out of the entire 2-hour span.

Procedure

After obtaining informed consent and demographic information, participants were first randomly assigned to either the Control condition in which there was no ‘try hard’ instruction between trials or, assigned to the experimental condition (Try Hard condition) in which prior to some of the trials they were prompted with an instruction to ‘try hard.’ Participants were tested individually in a dimly lit room where they completed the psychomotor vigilance task while pupil diameter was simultaneously recorded. After calibrating the eye tracker, participants performed a variant of the psychomotor vigilance task. Participants were first presented with a row of X’s (XXXXXXXX) or, if in the experimental condition, the instruction to ‘try hard’ (TRY HARD) on screen for 1000 milliseconds (msec) before certain trials. Next, participants were presented with a row of five black fixation crosses in the middle of the screen on a white background for 2000 msec. Participants were then presented with a row of zeros in blue Arial font 24 (visual angle 1.21°) in the center of the screen. The task required the participants to press the spacebar as quickly as possible once the numbers started changing after a pseudorandom variable inter-stimulus interval, ISI, (ISI: wait time before the stimulus; time between 0s and changing of value) which ranged anywhere from two to ten seconds. After pressing the spacebar, the response time was left on screen in red for one second to provide feedback to the participants. Following feedback, a 500 msec blank screen was presented, and then either the next trial began, or participants were presented with a thought probe on the screen. In the experimental condition, on 20% (pseudo-random) of the trials, participants were presented with the instruction to ‘try hard’ on the following trial. Participants performed 120 trials, and the task lasted approximately 30 minutes. The dependent variables included mean reaction time (RT), as well as the number of trials with RTs> 500 msec (Dinges & Powell, 1985). This latter measure was chosen given that it is the standard measure of lapses used in this task (Lim & Dinges, 2008; Unsworth & Robison, 2016). Thought probes were also presented throughout the task that asked participants if on the immediately preceding trial, they were (1) on-task, (2) experiencing task-related interference, (3) experiencing external distraction, (4) intentionally mind-wandering, (5) unintentionally mind-wandering, or (6) mind-blanking. Participants responded by pressing the appropriate number on the keyboard. Responses 3-6 were considered attentional lapses (aka “off-task thoughts;” external distraction, mind-wandering, and mind-blanking).



XXXXXXXX

Try Hard

Figure 4. The initial screen participants saw before trials depending on which condition they were randomly assigned.

Those in the Control condition always saw the left image prior to each trial and those in the Try Hard condition saw the right image prior to certain trials.

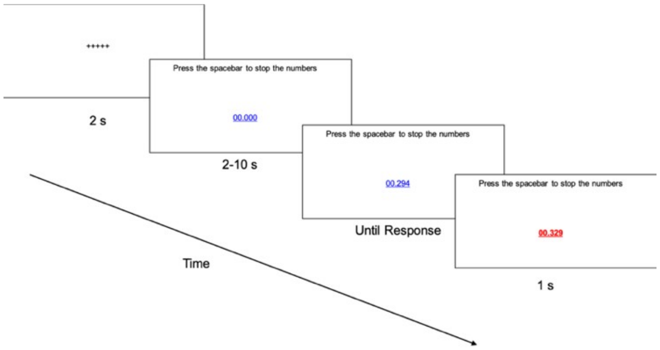


Figure 5. Progression of the task

Press the Spacebar to stop the numbers

00.000

Figure 6. After the initial screen and the fixation crosses, participants were shown this slide which remained on their screen between 2 to 10 seconds before the 0s changed in value (varying in time between trials).

This was the time period (ISI) in which the preparatory phase of pupillary response was examined.

Eye Tracking

Pupillary responses were recorded during the preparatory phase (during the ISI) and during the task (once the numbers began to change). Pupil diameter was continuously recorded binocularly at 120 Hz using a Tobii T120 eye tracker. Participants were seated approximately 60 centimeters from the monitor with the use of a chinrest. Stimuli was presented on the Tobii T120 eye tracker 17-inch. monitor with 1024 × 768 screen resolution. Data from each participant's left eye was used. Missing data points due to blinks, off-screen fixations, and/or eye tracker malfunctions were removed when analyzing the data. Pre-trial baseline pupil size was computed as the average pupil diameter during the fixation cross screen (2000 msec). Pupillary responses during the ISI were corrected by subtracting out the pre-trial baseline and locked (time at this point is zero) to when the numbers appeared on screen on a trial-by-trial basis for each participant. To examine the time course of pupillary responses during the ISI, pupillary data was averaged into a series of 200 msec time windows following the appearance of the numbers for each trial. Phasic (i.e., task-evoked) responses to the onset of the stimulus (changing of the numbers) were corrected by subtracting out the last 200 msec of the ISI and locked to when the numbers began counting on a trial-by-trial basis for each participant. To examine the time course of the phasic pupillary responses, pupillary data was averaged into a series of 20 msec time windows following stimulus onset for each trial. The dependent measure is the average phasic pupillary response which includes the peak in pupil size given a clear peak is present in the waveform. Specifically, the peak is defined as the maximum pupillary dilation following stimulus onset for each trial and each participant.

Results

Following data collection, data was analyzed using SPSS and Jamovi. Data was split into the following three categories: behavioral results, preparatory pupillary response and phasic (task-evoked) pupillary response. Within each category, analyses were organized by first examining between-subject effects (Try Hard condition vs Control condition) followed by within-subject effects of the Try Hard condition (Try Hard trials vs Standard trials).

Behavioral Results

Between-Subject Effects (Try Hard Condition vs Control Condition)

An independent samples *t*-test revealed that individuals in the Try Hard condition had statistically significant faster mean RTs (*M* = 359.30, *SD* = 39.74) when compared to individuals in the Control condition (*M* = 397.57, *SD* = 62.32), *t*(80) = 3.30, *p* = .001, Cohen's *d* = .728. Not only were people in the Try Hard condition faster in their overall performance, but they also reported a lower proportion of off-task thought (*M* = .50, *SD* = .25) than people in the Control condition (*M* = .62, *SD* = .25). Examining the number of trials with RTs > 500 msec (i.e., lapses in attention) revealed a similar finding, insofar that the total number of attentional lapses was lower for those in the Try Hard condition (*M* = 7.08, *SD* = 6.41) than those the Control condition (*M* = 12.98, *SD* = 11.21), *t*(80) = 2.91, *p* = .005, Cohen's *d* = .642 and achieved statistical significance. Collectively, these results are consistent with our hypothesis by suggesting that overall performance is much better in the Try Hard condition compared to the Control condition. See Table 1 for more details.

Table 1. Differences in mean response time, proportion of on-task thought, proportion of off-task thought, proportion of task-related interference, and total number of lapses between the Control condition (*N*=42) and Try Hard condition (*N*=40)

	Condition	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
Mean Response time	Control	42	397.57	62.32	9.62
	Try Hard	40	359.30	39.74	6.28
On Task	Control	42	.16	.22	.034
	Try Hard	40	.28	.26	.041
Off Task	Control	42	.62	.24	.038
	Try Hard	40	.50	.25	.040
Task Related Interference	Control	42	.22	.21	.032
	Try Hard	40	.22	.13	.020
Lapse	Control	42	12.97	11.21	1.73
	Try Hard	40	7.07	6.41	1.01

Within-Subject Effects (Try Hard Trials vs Standard Trials)

Among those assigned to the Try Hard (experimental) Condition, a paired samples *t*-test revealed no statistically significant difference in mean RTs (msec) when comparing Standard trials (M = 360.20, SD = 40.35) to Try Hard trials (M = 355.73, SD = 45.11), $t(39) = 0.995$, $p = .326$, Cohen's $d = .157$. The proportion of off-task thought also did not show a statistically significant difference between Standard trials (M = .514, SD = .289) and Try Hard trials (M = .486, SD = .247), $t(39) = 0.987$, $p = .330$, Cohen's $d = .156$. Similarly, the proportion of trials with RTs > 500 msec (i.e., lapses in attention) did not demonstrate a statistically significant difference between Standard trials (M = .058, SD = .054) and Try Hard trials (M = .063, SD = .042), $t(39) = 0.441$, $p = .661$, Cohen's $d = .070$. Taken altogether, these results suggest that there were no differences across trials in either performance (as measured by mean RTs) or attentional lapses (indexed with off-task thoughts and the slowest RTs). See Table 2 for more details.

Table 2. Differences in mean response time, proportion of on-task thought, proportion of off-task thought, proportion of task-related interference, and total number of lapses across trial type (Standard vs Try Hard trials) within participants in the Try Hard condition (N=40)

	Trial Type	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
Mean Response time	Standard	40	360.20	40.35	6.38
	Try Hard	40	355.73	45.11	7.13
On Task	Standard	40	.29	.31	.050
	Try Hard	40	.26	.23	.036
Off Task	Standard	40	51	.29	.046
	Try Hard	40	.49	.25	.039
Task Related Interference	Standard	40	.19	.15	.024
	Try Hard	40	.25	.17	.023
Lapse	Standard	40	.058	.054	.0086
	Try Hard	40	.063	.076	.012

Preparatory Pupillary Response-Prior to stimulus onset

Between-Subject Effects (Try Hard Condition vs Control Condition)

A 2 (Condition: Control vs. Try Hard; between-subjects factor) x 50 (Bin; within-subjects factor) repeated measures ANOVA revealed no statistically significant main effect of Condition on mean pupillary response prior to the appearance of the stimulus, $F(1, 80) = .49$, $p = .488$, partial $\eta^2 = .006$. However, the repeated measures ANOVA did show a statistically significant main effect of Bin, $F(49, 3920) = 2.18$, $p < .001$, partial $\eta^2 = .027$; the pupil size tends to go down initially then back up. Importantly, though, there was also a statistically significant interaction between Bin and Condition, $F(49, 3920) = 3.10$, $p < .001$, partial $\eta^2 = .037$. Figure 7 demonstrates that only for participants in the Try Hard condition, the pupil size increased at the end of the preparatory period (as the stimulus is about to appear). However, for people in the Control condition, the pupil stayed small. These results suggest participants were preparing more in the Try Hard condition than the Control condition.

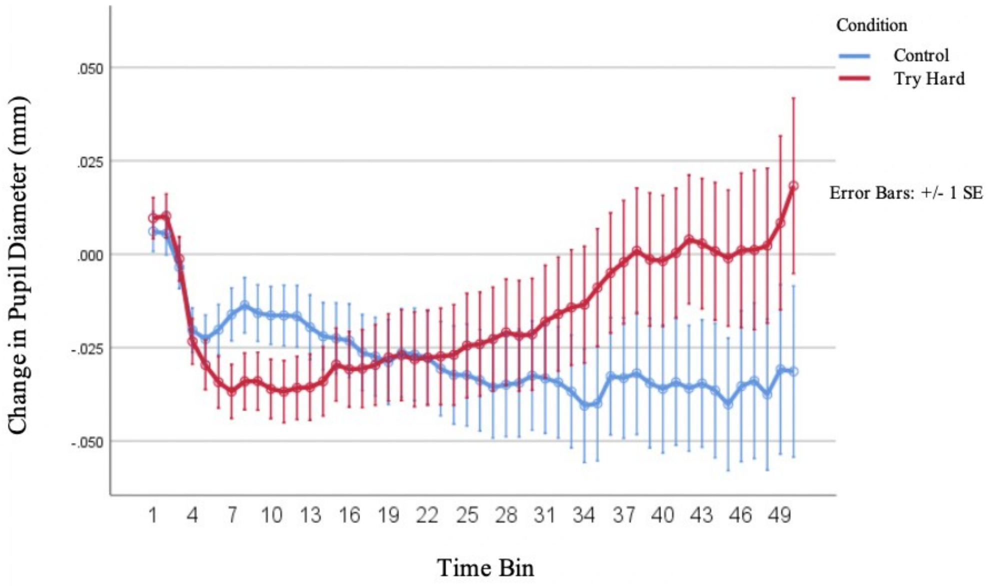


Figure 7. Average change in pupil diameter (mm) across 50-Time Bins (each 200 msec) between Control and Try Hard conditions during the preparatory phase.

Within-Subject Effects (Try Hard Trials vs Standard Trials)

Next, we submitted pupillary responses (before stimulus onset) to a 2 (Trial Type: Try Hard vs. Standard; within-subjects factor) x 50 (Time Bin; within-subjects factor) repeated measures ANOVA. Results revealed a statistically significant main effect of Trial Type, $F(1, 37) = 8.374$, $p = .006$, partial $\eta^2 = .185$, suggesting Try Hard trials had larger pupillary responses ($M = .005$, $SE = .013$) overall relative to Standard trials ($M = -.022$, $SE = .013$). The repeated measures ANOVA further revealed a statistically significant main effect of Bin, $F(49, 1813) = 3.539$, $p < .001$, partial $\eta^2 = .087$; as demonstrated in Figure 8, during the preparatory period for both trials, pupil size decreased initially but then gradually increased. The interaction between Trial Type and Bin was not statistically significant ($p = 1.00$), meaning the effect of Trial Type on pupillary response prior to stimulus onset did not change as a function of time bin.

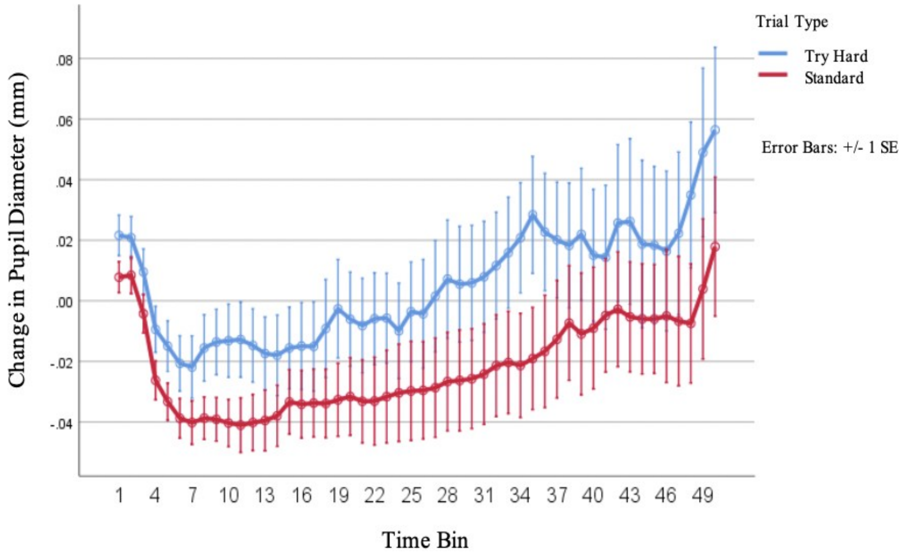


Figure 8. Average change in pupil diameter (mm) across 50-Time Bins (each 200 msec) comparing Try Hard and Standard trials within the Try Hard condition during the preparatory phase.

Phasic Pupillary Response-After stimulus onset

Between-Subject Effects (Try Hard Condition vs Control Condition)

The 2 (Condition: Control vs. Try Hard; between-subjects factor) x 55 (Time Bin; within-subjects factor) repeated measures ANOVA revealed the main effect of Condition was not quite statistically significant, $F(1, 80) = 3.90$, $p = .052$, partial $\eta^2 = .046$. There was a statistically significant main effect of Bin, $F(54, 4320) = 63.61$, $p < .001$, partial $\eta^2 = .443$, shown by the classic phasic pupillary response seen in both conditions. Figure 9 shows that once the stimulus appeared, the pupil began to increase in size and then decreased. Finally, there was a statistically significant interaction between Bin and Condition, *F*(54, 4320) = 3.15, $p < .001$, partial $\eta^2 = .038$, suggesting the effect of Condition on pupillary response depended on Bin. Figure 9 reveals that differences in TEPRs between conditions got larger as time increased. That is, people in the Try Hard condition had a larger peak than people in the Control condition. This suggests participants in the Try Hard condition utilized more effort when the numbers started changing in value compared to participants in the Control condition.

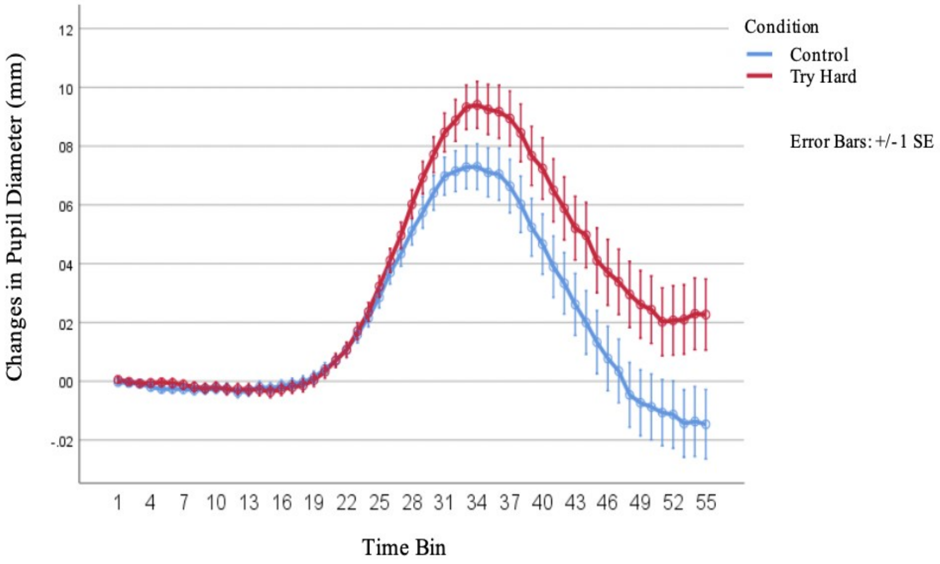


Figure 9. Average change in pupil diameter (mm) across 50-Time Bins (each 20 msec) between Control and Try Hard conditions during the phasic pupillary response.

Within-Subject Effects (Try Hard Trials vs Standard Trials)

Finally, we submitted TEPRs (after stimulus onset) to a 2 (Trial Type: Try Hard vs. Standard; within-subjects factor) x 55 (Time Bin; within-subjects factor) repeated measures ANOVA. Results revealed a lack of a statistically significant main effect of Trial Type, *F*(1, 39) = .085, $p = .772$, partial $\eta^2 = .002$, suggesting no differences in overall TEPRs across trials. However, results did reveal a statistically significant main effect of Bin, $F(54, 2106) = 27.42$, $p < .001$, partial $\eta^2 = .413$. As shown in Figure 10, pupils tended to increase in size then decrease following the appearance of the stimulus. The interaction between Trial Type and Bin was not statistically significant ($p = 1.00$), meaning the effect of Bin on TEPRs after stimulus onset did not differ based on Trial Type. Taken altogether, these results suggest similar levels of effort were devoted to the stimulus (once it appeared onscreen) regardless of whether one received a Try Hard trial or a Standard trial.

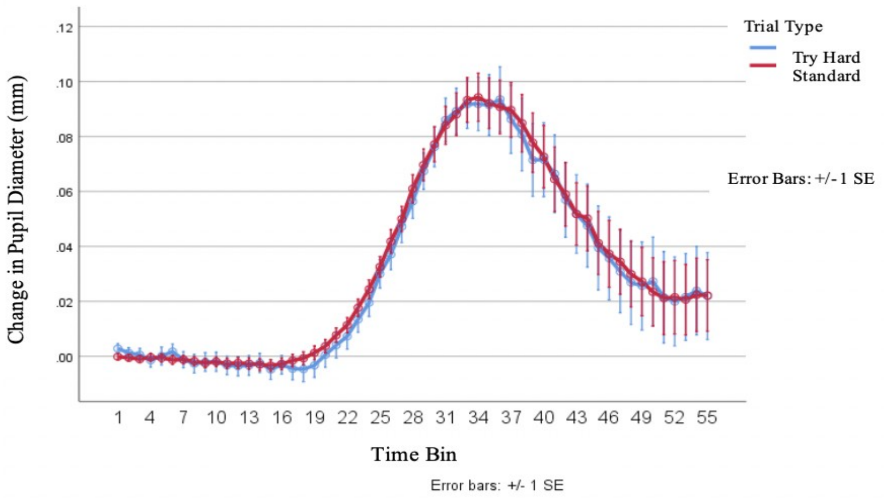


Figure 10. Average change in pupil diameter (mm) across 50-Time Bins (each 20 msec) comparing Try Hard and Standard trials within the Try Hard condition during the phasic pupillary response.

Discussion

In the present study, variations in performance, lapses in attention, and pupillary responses were examined between Try Hard and Control conditions. For those assigned to the Try Hard condition, we also examined the same variables across Try Hard and Standard trials. Examination of behavioral results indicate a statistically significant improvement in performance between the conditions. Comparison of the two conditions shows increased mobilized effort in the Try Hard condition, not only supporting our hypothesis, but also the results of the study by Steinborn et al. (2017). That is, results are consistent with the notion that individuals have a reserve of effort which can be mobilized in order to enhance performance. Improved performance in the Try Hard condition was demonstrated by faster average RTs. Critically, however, this enhanced performance was also accompanied by fewer off-task thoughts (determined from thought probes), as well as fewer attentional lapses as indicated by the number of trials with RTs> 500 msec. Moreover, people in the Try Hard condition displayed a ramp up in pupil size towards the end of the preparatory period, whereas people in the Control condition showed no such increase (Figure 7). Not only that, but individuals in the Try Hard condition also showed a larger peak dilation in response to stimulus onset than did individuals assigned to the Control condition (Figure 9). Hence, not only did participants in the Try Hard condition put forth more attentional effort in preparation for stimulus onset (relative to participants in the Control Condition), but they also utilized more effort when the numbers started to change in value.

Interestingly, a lack of discrepancies was observed across trials within the Try Hard condition. Specifically, within the Try Hard condition, there was no statistically significant difference in performance based on the aforementioned variables (i.e., control trials resulted in similar levels of performance and TEPRs as trials with the ‘try hard’ instruction). A major implication of this result is that when individuals are presented with the instruction to ‘try hard’ the first-time, they may naturally attempt to maintain that same level of increased effort throughout the entirety of the task, even during the Standard trials. This may imply that repeated instructions to ‘try hard’ before randomly determined trials may not necessarily be responsible for the maintenance of higher effort levels throughout the task. In other words, it is possible that once individuals increase their effort levels, they are able to maintain it at that level without subsequent instructions to ‘try hard.’

As previously mentioned, the results of the present study are consistent with prior work (Kleinsorge, 2001; Steinborn et.al, 2017) suggesting that increased effort presents itself through improved performance (faster mean RTs) accomplished by the use of ‘try hard’ instructions. This study built upon this existing literature by further revealing that the ‘try hard’ instruction serves to produce changes in the pupillary response both before and after stimulus onset. Specifically, for the Try Hard condition, the pupil began to ramp up in size and continually increase for the duration of the ISI, demonstrating active preparation and mobilization of effort by individuals to enhance performance. Conversely, the Control condition showed a continuously decreasing pupil size, suggesting that participants were not maintaining high levels of attention (Figure 7). The decrease in pupil size over time indicates that as the wait time for the stimulus increased, effort levels of participants in the Control condition also decreased proportionally.

Unsworth et al. (2016) and Steinborn et al. (2017) found similar results in that the longer the ISI of the task, the worse the performance was. That is, increased wait time results in slower response times, presumably due to decreased effort levels causing increased lapses in sustained attention. Our results support this notion as the Control condition had slower mean RTs, more off-task thought and more behavioral lapses, as well as decreased effort levels evident through smaller preparatory and task-evoked pupillary responses. The differences between the pupillary responses indicate that participants in the Try Hard condition were preparing more by mobilizing more effort than those in the Control condition. However, as mentioned earlier, Try Hard trials and Standard trials displayed similar pupillary responses during the preparatory phase (Figure 8). Both trial types had an initial dip followed by a ramp up in pupil size. The ramp up occurred regardless of whether the trial had a ‘try hard’ instruction, demonstrating that individuals in this condition were, overall, attempting to perform better by increasing their effort levels while waiting.

There were also similarities between conditions for the task-evoked pupillary response. Both conditions displayed a classic phasic pupillary response (Figure 9) with an initial increase in pupil size once the stimulus was presented and then a gradual decline in size afterwards. In both conditions, individuals were attending to the task. Differences in effort levels between the two conditions is highlighted by the varied peak levels. The Try Hard condition had a larger peak in pupil size supporting our hypothesis that individuals in this condition would be able to mobilize more effort. The Try Hard condition also ended with a pupil larger in size than what was initially began with, though the Control condition ended with a smaller than initial pupil size. This implies that not only were participants in the Try Hard condition able to mobilize more effort due to the ‘try hard’ instructions, but they were also able to sustain a higher level of effort for longer. Ending with a larger average pupil size may be representative of the ability for individuals in the Try Hard condition to maintain higher levels of attention throughout the task regardless of trial type as discussed earlier. The task-evoked pupillary response within the Try Hard condition further supports the conclusion that trial type in this condition had no effect on performance. Both trial types illustrated the same classic phasic pupillary response but unlike between conditions, the peaks of both trial types were also identical (Figure 10). Hence, once individuals were encouraged to increase effort levels, they were more capable of holding effort at that level even during Standard trials.

Our results suggest the observed increase in performance for those in the Try Hard condition is at least partly due to these individuals experiencing less attentional lapses. Future research should delve further into the Try Hard condition to develop a deeper understanding of how exactly the ‘try hard’ instruction impacts performance and attentional lapses. Are repeated instructions necessary to maintain high levels of attention and effort or are those elevated levels maintained after the initial instruction? Further research could create a task in which one condition presents the ‘try hard’ instruction pseudo-randomly as this study did and have another condition in which the ‘try hard’ instruction is presented only at the beginning of the task. This would help to distinguish whether effort levels are increased and maintained after each round of instruction or if they are held constant after initial elevation from the first instruction.

As with all studies, there are limitations in the experimental design that may have impacted the results found. One such limitation in this study is having participants complete an hour and a half's worth of other attention and memory-based tasks prior to this study's specific task. This would result in individuals who are more mentally fatigued by the time they reach this study's specific task. This limitation may have resulted in smaller differences between conditions than may have been found if participants partook in this task without anything beforehand. Some other weaknesses include the fact that the present study used an artificial laboratory task to examine sustained attention; therefore, it may be difficult to generalize these results to more complex, real-world situations. Moreover, our sample consisted of college-level undergraduate students. Thus, it is difficult to generalize these results to other populations that may have different education levels. Finally, because the pupillary response is relatively slower (taking a few seconds to develop), the present study may be missing other responses that evolve at a fast rate.

Conclusion

The overall finding of this study demonstrates evidence that instructions to ‘try hard’ were successful in increasing effort output resulting in better performance seen through faster response times, and less indication of off-task thoughts and attentional lapses. Furthermore, the pupillary response for those who increased effort (those in the Try Hard condition) showed larger pupil dilation during the preparatory phase and a larger pupillary peak during the task. This supports our hypothesis that individuals have the capability to mobilize effort in order to perform better and that this is also demonstrated by dilation of the pupil. More nuanced implications of this study show that within the Try Hard condition, continued instructions to ‘try hard’ do not appear to have a continuous impact on improving the performance of individuals. It appears that the initial ‘try hard’ instruction resulted in elevated effort levels that were sustained throughout the task regardless of trial type as there was no significant difference in performance or task-evoked pupillary response across the Try Hard and Standard trials.

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