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Looking around: comparing saccades and fixations among designers with and without ADHD

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ABSTRACT: Engineering design tasks are cognitively complex and there is a growing interest in understanding the neurocognitive processes involved in design. Consequently, researchers are increasingly using bio-physical markers such as eye tracking to study design neurocognition. However, these studies are largely correlational, and little is understood about the construct validity of eye-tracking metrics such as fixation durations and saccade frequency. Moreover, these studies rarely account for non-design factors such as neurodivergence (e.g., ADHD) on eye-tracking metrics during design. We aim to examine this research gap through a causal-comparative study with designers with and without ADHD, performing divergent and convergent design tasks. Our findings call for a deeper investigation into the construct validity of eye-tracking metrics while considering a broad range of external factors.

KEYWORDS: design cognition, ADHD, conceptual design, creativity

1. Introduction

Advancements in neurocognition, such as Cognitive Load Theory (CLT) and visual attention research, have enabled researchers to better understand individual factors that influence the design process. Cognitive load describes how our working memory systems have limited capacity; therefore, it is critical to avoid overstraining these processes to maximize learning and performance (Sweller, 1988). Furthermore, visual attention enables us to store and retrieve information in working memory (Theeuwes et al., 2011) while ignoring irrelevant stimuli (Payne & Allen, 2011).

Since cognitive overload (Zimmerer & Matthiesen, 2021) and visual attention (Ahmed et al., 2021) can influence the design processes of engineers, it is beneficial to investigate designers' neurocognition. One way of doing so is with the use of various eye-tracking proxies such as pupil diameter, gaze points, saccades, and fixations which offer insight into neurodevelopment, learning, and neuroplasticity (Eckstein et al., 2017). Moreover, external eye-tracking devices are non-invasive, portable, and can be adapted to low-resource settings, making them ideal in research settings (Forssman et al., 2017). Therefore, studying cognitive load and visual attention through eye-tracking metrics could help us better understand designers' cognitive processes and identify opportunities to manage them.

Despite the growing interest in studying designers' neurocognition using behavioural and biological markers (Gero & Milovanovic, 2020), *few studies have explored how eye-tracking measures vary when designers perform different types of design tasks*. That is, we are unsure whether these metrics change when designers perform divergent and convergent design tasks. Prior research has demonstrated that considering individual neurocognitive and performance strengths provides insight into how teams can best perform (Williams Woolley et al., 2007). Moreover, as discussed in Sections 2.2 and 2.3, these metrics could be influenced by non-design factors such as cognitive disorders (e.g., attention deficit hyperactivity disorder (ADHD)). *Few studies on design neurocognition account for the effects of neurodiversity on design and cognitive performance.*

We highlight the impact of ADHD, as it is one of the most common psychiatric disorders (Kooij et al., 2019). Additionally, ADHD causes increased cognitive load (Seymour et al., 2016) and challenges with visual attention (Lin et al., 2021), both of which could impact design performance. Despite the potential implications of ADHD in design and the high rates of the disorder, limited research has investigated the impact of ADHD on design cognition during convergent and divergent thinking tasks. Therefore, we aim to examine this gap by studying saccades and fixations among designers with and without ADHD, when performing design tasks. Before doing so, we review prior research on the use of these metrics in neurocognition.

2. Related work

Our aim in this paper is to study the effects of ADHD on saccade frequency and fixation durations when performing divergent and convergent thinking tasks. Before doing so, we review prior work on these topics, as discussed next.

2.1. What are saccades and fixations, and why are they important?

Saccades are eye movements that enable individuals to scan and later process environmental stimuli. One type, reflexive saccades, is externally controlled by the sudden appearance of stimuli in the environment, prompting an individual to change their gaze. Internal saccades occur when an individual intentionally moves their focus to place stimuli into their central vision through their fovea. Internal saccades include memory saccades (e.g., when an individual connects stimuli to prior exposure), predictive saccades (i.e., when an individual predicts where stimuli may be present), and spontaneous saccades (i.e., when individuals move their eyes without a specific target in mind) (Pierrot-Deseilligny et al., 1995). Saccades are caused by various areas of the cortex that indicate higher-order cognitive functions, making them a valuable tool for understanding neurocognition (McDowell et al., 2008).

Fixations occur between saccades when an individual "fixates" on a specific target. The ability to process visual input is contingent on our ability to control fixations (Upadhyayula & Flombaum, 2020). Two types of small eye motions can occur during fixation: drift and micro-saccades, illustrating that even fixations do not result in complete stillness of the eyes (Engbert & Kliegl, 2004). Various brain mechanisms enable fixations to occur, such as bilateral activity in the medio-posterior cerebellum and superior colliculi (Krauzlis et al., 2017). Like saccades, fixations can provide insight into neurocognitive processes such as memory (Schwedes & Wentura, 2019), attention, and language processing (Henderson et al., 2018).

Therefore, a better understanding of saccades and fixations could offer important insights into their complex origins and causes. Furthermore, such an understanding could reveal how important aspects of designers' neurocognition relate to their performance, especially when working with external stimuli and design tools. However, as previously mentioned, little research has examined designers' saccades and fixations when performing different design tasks, and we aim to explore this research gap. Toward this aim, we review prior work on contextual factors that influence saccades and fixations.

2.2. What are some contextual factors that influence saccades and fixations?

Saccades and fixations are the result of many internal and external factors. Individuals with disorders that affect the frontal lobe or basal ganglia, such as schizophrenia, Parkinson's disease, and ADHD, may experience a lack of inhibition in the frontal eye fields and superior colliculus, leading to excess saccades (Munoz & Everling, 2004). Children (Ross et al., 1994) and individuals with autism (Johnson et al., 2016) or dyslexia (Tiadi et al., 2016) also tend to experience higher numbers of saccades more generally. In addition to various disorders, the presence and intensity of visual stimuli can influence saccades in individuals (L. Wang & Stern, 2001). For example, salient distracters affect fixation durations and saccade velocities when individuals learn new information (McColeman & Blair, 2013). Along with stimuli and distractors, various attention and memory mechanisms influence saccades, as individuals must remember where stimuli are to refocus their gaze on targets (C.-A. Wang et al., 2018). Knowledge of where and when an impending target is can increase the number of saccades and decrease saccade latency (Gagnon et al., 2002).

Saccade frequency and fixation duration can provide an understanding of visual attention and where individuals are looking (Jonikaitis et al., 2013). Saccades only occur when an individual is not focused on a fixation point, demonstrating a moment of disengaged visual attention (Fischer & Breitmeyer, 1987). Furthermore, saccades and fixations indicate cognitive load levels, as cognitive load and saccade frequency are often negatively correlated (Walter & Bex, 2021), whereas cognitive load and fixation durations are often positively correlated (Liu et al., 2022). Fatigue and arousal, two factors that are related to cognitive load (Souchet et al., 2022), can also implicate saccades and fixations (Chen et al., 2022). Saccade patterns are dependent on the time of day, as fatigue can decrease saccade speed and increase mean fixation duration (Cazzoli et al., 2014). Arousal and larger pupil dilation, however, shorten saccade latencies and heighten saccade velocity.

Taken together, many co-occurring factors - internal and external to the individual - influence saccades and fixations. One of these factors is the presence of cognitive disorders such as ADHD - an aspect that is little emphasized in design neurocognition. Understanding these complex relationships could guide design education and research that accounts for individual differences in designers' performance and needs based on their cognitive characteristics. Therefore, in this study, we aim to make a first attempt at studying saccade frequency and fixation duration with individuals performing different design tasks. Before doing so, the implications of saccades and fixations in design research are reviewed.

2.3. Why should we study saccades and fixations in design?

Saccades and fixations reveal insights into attention and memory, among other neurocognitive processes that may be critical in design (Hu & Shepley, 2022; Walter & Bex, 2021). For example, cognitive overload could negatively impact design performance, and therefore, measuring cognitive load using saccades and fixations could be useful in improving design performance (Walter & Bex, 2021). Similarly, engineering designers rely on their visual attention to analyse stimuli and process information that could help them make design decisions (Ahmed et al., 2021). Therefore, eye-tracking metrics could be used to measure patterns of visual attention and predict designers' use of stimuli.

In addition to cognitive load and visual attention, effective design processes rely on convergent and divergent thinking (Pathan et al., 2016). Both types of design tasks require visual attention, with divergent thinking requiring dispersed visual scanning compared to focused attention in convergent thinking (Maheshwari et al., 2022). Moreover, cognitive overload impedes creativity performance, and increasing the demands on working memory can reduce flexibility (Orzechowski et al., 2023) and fluency (Rodet, 2022) scores in divergent thinking tasks. Cognitive overload also leads to higher levels of risk-taking in convergent thinking tasks (Zhou et al., 2017) and can create challenges in the semantic search process, negatively affecting the ability to achieve an optimal answer.

However, the relationships between eye tracking and design performance are complicated among individuals with ADHD. ADHD is one of the most common psychiatric disorders (Kooij et al., 2019) and causes deficits in working memory and weaker functioning of the prefrontal cortex (Arnsten, 2009). ADHD is associated with increased cognitive load, which can heighten impulsivity (Seymour et al., 2016). Similarly, individuals with ADHD exhibit challenges with visual attention (Lin et al., 2021) and may struggle with saccade and fixation control (Munoz et al., 2003). As previously discussed, both visual attention and cognitive load impact design performance. Therefore, designers with and without ADHD may vary in their visual attention and cognitive load when performing divergent and convergent thinking tasks (Kimball & Prabhu, 2024). These differences may manifest in their eye-tracking metrics, such as saccade frequency and fixation duration. However, little research has studied these differences, and we aim to explore this research gap.

2.4. Research questions

Our aim in this paper is to compare saccade frequency and fixation duration between participants with and without ADHD when performing convergent and divergent thinking tasks. Toward this aim, we seek to answer the following research questions:

1. RQ1: How does saccade frequency compare between individuals with and without ADHD when performing convergent and divergent-thinking design tasks?
2. RQ2: How does fixation duration compare between individuals with and without ADHD when performing convergent and divergent-thinking design tasks?

To answer these RQs, we conducted a causal-comparative study, and the details of our data collection methods are discussed next.

3. Data collection methods

To answer these research questions, we conducted a causal-comparative study comprising a divergent and convergent design task. The details of the data collection methods are discussed in the remainder of this section. It should be noted that the data used in this study were collected as part of a larger study, some results of which were presented by Kimball & Prabhu (2024).

3.1. Participants

Participants were recruited from a liberal arts college in the Northeastern United States. Third and fourth-year engineering students with and without ADHD were eligible to participate, leading to 10 participants with ADHD and 14 without ADHD. Of the 24 participants, 7 identified as male, 15 identified as female, and 2 identified as agender or preferred not to answer when asked about their gender identity. 19 participants identified as White, three as Asian, one as Black, and one as Arab when asked for their race/ethnicity. The demographic data were collected in the form of open-ended surveys based on the guidelines put forth by (Hughes et al., 2022). Additionally, these data were collected in the form of a post-study survey to minimize stereotype threat (Spencer et al., 2016) and performance expectancy (Brock et al., 1965). Participants were categorized into the ADHD/non-ADHD groups based on self-reported data on a formal diagnosis. Some participants reported that they may have ADHD or demonstrate some common symptoms but do not have a formal diagnosis and these participants were excluded from our study.

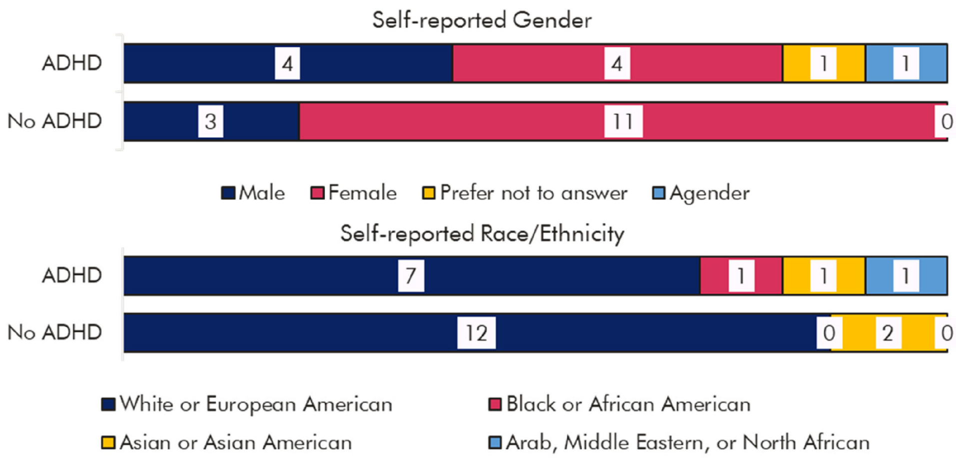

Figure 1. Distribution of participants self-reported gender and race/ethnicity

3.2. Procedure

The data collection procedure comprised of two parts, a verbal fluency test and a design task, the details of which are discussed next.

3.2.1. Verbal fluency baseline assessment

Participants first completed a verbal fluency assessment based on the Controlled Oral Word Association Task (Spreen & Risser, 1998), where they were prompted to provide as many words as possible within a specific category (e.g., words that began with the letter "A") within one minute. Verbal fluency is influenced by factors such as anxiety and depression (Kryza-Lacombe et al., 2024), language impairments (Gonçalves et al., 2018), executive functioning challenges (Hedman et al., 2022), effort (Cohen et al., 2001), and fatigue (Cockshell & Mathias, 2010). Since the design task prompted participants to write down their design ideas with words, using the verbal fluency assessment as an exclusion criterion ensured that participants would be able to generate ideas in a short period and avoid poor semantic access as a confounding variable. Their performance on the verbal fluency task was used as the exclusion criterion since the subsequent design task relies on the ability to come up with as many ideas as possible for a given problem and describe them in words.

3.2.2. Divergent and convergent thinking design tasks

After completing the verbal fluency test, participants were asked to complete a divergent and convergent thinking design task in that order. Participants were eye-tracked as they performed these tasks using the Tobii Pro Glasses 3 eye tracker. Specifically, participants were prompted to complete a divergent thinking design task where they were presented with the following design prompt and asked to generate as many solutions as possible and write them down on paper within 10 minutes:

> *The College prides itself on fostering a collaborative academic environment. This environment is possible largely due to the design of the student spaces. There is a trade-off, however; with some of these design choices (e.g., glass walls) comes distraction. You are tasked with generating new solutions that enable collaboration in your desired study spaces while limiting distractions as much as possible. There are no wrong answers – solutions of all kinds are welcome!*

Participants were encouraged to generate original, out-of-the-box ideas and devise as many solutions as possible in this divergent thinking task. After generating ideas, participants were tasked with a convergent thinking task, wherein they were asked to select the idea that best met the requirements of the problem. Specifically, they were asked to select one idea from their generated ideas that best promoted collaboration, reduced distraction, and was as original and practical as possible. Participants were given two minutes to complete the idea selection task.

3.3. Metrics

Cognitive load and visual attention were measured with two eye-tracking proxies: saccade frequency (saccades per second) and average fixation duration (in seconds). These metrics were selected to expand our prior work on pupil diameter (Kimball & Prabhu, 2024). Saccade frequency and average fixation duration tend to be inversely related, where individuals with more frequent saccades exhibit longer fixations. Increased saccade frequency and decreased fixation durations are associated with lower cognitive load, and decreased saccade frequency and increased fixation duration indicate higher cognitive load levels.

The eye-tracking recordings were processed with Tobii Pro Lab to extract the parameters of interest. We used the fixation gaze filter for data extraction as it is more suitable for small eye motions than the attention gaze filter. Each timestamp recorded a fixation or saccade, and we used Python to count the total number of saccades within each participant that indicated a "saccade" and divide this over the total time lapsed to derive a saccade frequency. Furthermore, we grouped consecutive "fixations" timestamps and measured the time between the beginning and end of the fixation, which we then averaged across each participant to derive an average fixation duration.

4. Data analysis and results

The data collected were analysed using quantitative methods. Specifically, we conducted two two-way ANOVAs with condition (i.e., ADHD and no-ADHD) and task type (i.e., divergent and convergent) as the independent variables. We used saccade frequency and average fixation duration as the dependent variables in each ANOVA. Before conducting the analysis, we tested the data for normal distribution and homogeneity of variances. We find that the data were not normally distributed ($p < 0.05$ for the Shapiro-Wilk Test), but there was homogeneity of variance within the two independent variable conditions in both ANOVA comparisons ($p > 0.05$ for Levene's test). Therefore, we conducted the two-way ANOVA despite the violation of the assumption of normality.

From the results of the two-way ANOVA, we observe no significant interaction between the condition and task when predicting saccade frequency ($F(1, 44) = 0.15$, SSE = 0.83, $p = 0.70$). Moreover, there were no significant differences in saccade frequency between individuals with and without ADHD ($F(1, 44) = 0.79$, SSE = 4.27, $p = 0.38$). However, we did see a significant effect of task type on saccade frequency ($F(1, 44) = 22.33$, SSE = 119.93, $p < 0.001$). Specifically, participants had higher saccade frequencies in the convergent thinking task (mean = 7.91 and SD = 2.87) than in the divergent thinking task (mean = 4.74 and SD = 1.51).

Furthermore, we observe no significant interaction between the condition and task when predicting fixation duration ($F(1, 44) = 0.38$, SSE = 0.04, $p = 0.54$). Moreover, there were no significant differences in fixation duration between individuals with and without ADHD ($F(1, 44) = 1.99$, SSE = 0.20, $p = 0.16$). However, we did see a significant effect of task type on fixation duration ($F(1, 44) = 18.24$, SSE = 1.82, $p < 0.001$). Specifically, participants had higher fixation duration during the divergent thinking task (mean = 0.87 and SD = 0.37) than during the convergent thinking task (mean = 0.49 and SD = 0.26). The results are summarized in Figure 1, and their implications are discussed in Section 5.

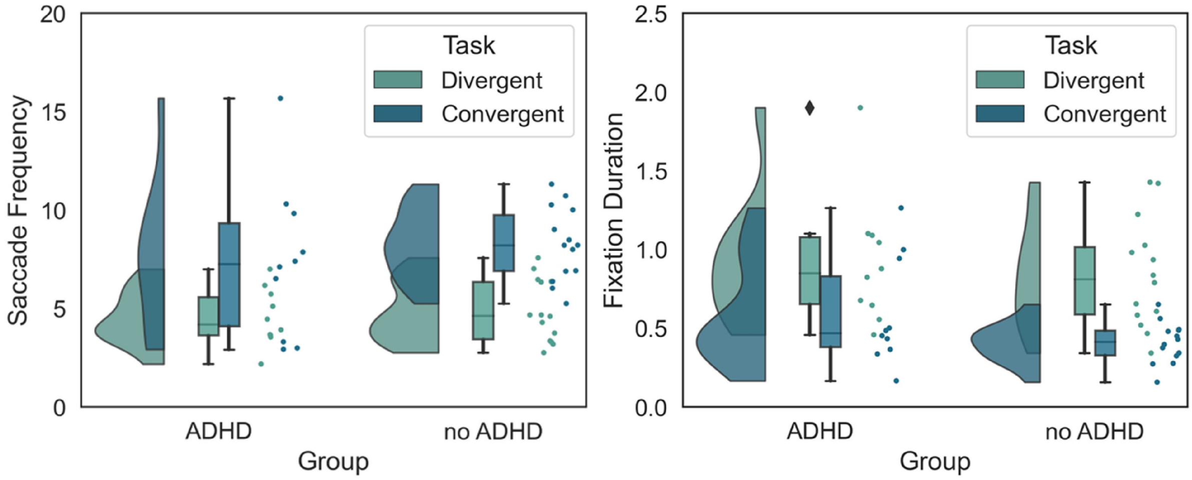

Figure 2. Comparing saccade frequency and fixation duration between participants with and without ADHD when performing divergent and convergent design tasks

5. Implications of our results for design research

Our aim in this study was to compare saccade frequency and fixation duration among designers with and without ADHD when performing divergent and convergent tasks. From our results, the following findings were observed:

1. Participants experienced more saccades during the convergent thinking task than the divergent thinking design task. On the other hand, participants experienced longer fixations during the divergent thinking design task than the convergent thinking design task.

Prior research has demonstrated that saccades and fixations are typically inversely related; that is, an increase in saccade amplitude is accompanied by a decrease in fixation durations and vice versa (Pannasch et al., 2008). Our findings align with these results by demonstrating that divergent thinking tasks may result in longer fixations and fewer saccades compared to convergent thinking tasks. These results reinforce our understanding that convergent and divergent design thinking tasks require different cognitive mechanisms and processes that can be reliably captured by using eye-tracking metrics. Despite this important insight, our results do not provide sufficient causal or construct information. *That is, we are unsure why saccades and fixations differ between convergent and divergent thinking tasks.* Our findings motivate such exploration towards establishing construct validity for these differences and suggest that eye-tracking metrics could be a reliable objective method to measure these differences in cognitive processes.

For instance, frequent saccades and shorter fixation durations during the convergent thinking task indicate more eye movements. This result could be attributed to different visual attention demands during the two tasks. Individuals are writing, rather than reading in divergent thinking tasks, and their attention may be more scattered as they are trying to think divergently. This result contradicts prior findings (see Section 1.3), indicating that divergent thinking is associated with more scattered visual attention. This contradiction could be attributed to eye movements required for the tasks themselves (e.g., writing, reading, and scanning) rather than the eye movements that occur from thinking convergently or divergently. Despite more eye movement in the convergent thinking task, visual attention may not have been scattered but could have been object-focused, which resulted in more rapid eye movements necessary for task completion. Furthermore, if cognitive load levels led to this difference, fewer saccades in the divergent-thinking task would be indicative of higher cognitive load levels than in the convergent-thinking tasks. Overall, the differences in eye-tracking metrics between the convergent and divergent tasks could be attributed to differences in attention and cognitive load demands, among other factors.

2. Saccade frequency and fixation durations did not differ between individuals with and without ADHD.

This result contradicts prior findings discussed in Section 1.2, which shows that individuals with ADHD tend to have higher levels of saccades (Munoz et al., 2003). Moreover, previous results have also found differences in creative performance between individuals with and without ADHD, especially when performing divergent thinking tasks (Kimball & Prabhu, 2024). This lack of significant differences in eye-tracking metrics could be attributed to the complexity of saccades and fixations and the neurocognitive constructs they represent. *Based on the data collected in our study, it is impossible to attribute eye-tracking metrics to one factor alone (e.g., cognitive load or visual attention).* Both tasks involved different visual stimuli and attentional demands, which could have affected eye-tracking metrics differently, and given the lack of causal understanding of eye-tracking metrics, these differences are difficult to untangle. It is also possible that the higher levels of eye movements in the convergent thinking task were not an indication of more scattered visual attention but, rather, were the result of more efficient, faster eye processing.
This observation further reinforces the need to establish construct validity of eye tracking metrics by employing methods such as multi trait-multi method approach for examining convergent and discriminant validity (Campbell & Fiske, 1959). For example, future research could examine the fixation points to understand how visual attention influenced saccades and fixation. Researchers could also explore how different statistical moments (e.g., mean and variance) of time-series eye-tracking metrics could be used to represent cognitive factors such as cognitive load (Cass & Prabhu, 2025). Finally, future studies could include self-report measures (e.g., NASA-TLX) and parallel task processing (e.g., the Stroop Test) to understand how cognitive load influences eye-tracking metrics. Researchers could also consider removing visual stimuli and focusing on eye-tracking metrics in verbal/auditory tasks to explore differences in eye-tracking metrics based on different stimuli and information processing modalities.

6. Concluding remarks, limitations, and directions for future work

Our aim in this study was to compare saccade frequency and fixation duration among designers with and without ADHD when performing divergent and convergent tasks. Toward this aim, we conducted a causal-comparative study with participants with and without ADHD involving divergent and convergent design thinking tasks. From the results, we see that participants showed greater saccade frequency and lower fixation duration when performing the convergent thinking task compared to the divergent thinking task. This result suggests that convergent and divergent thinking tasks employ different cognitive mechanisms and that eye-tracking metrics could be used to reliably measure these differences. However, no differences were observed between participants with and without ADHD. Therefore, the differences in eye-tracking metrics could be attributed to several contextual factors and individual differences, calling for a deeper understanding of the construct validity of eye-tracking metrics.
Despite the important insights obtained from the results of our study and the new directions for research illuminated by them, our study has some limitations. First, participants with ADHD often exhibit additional co-existing conditions such as autism (Rong et al., 2021), and individuals with autism tend to show high levels of saccades (Kemner et al., 1998). Similarly, individuals with ADHD can experience heightened levels of saccades due to attention and decreased inhibition. Therefore, it would be helpful to have a baseline of saccades and fixations before engaging in the task to better understand within-subject differences relative to a baseline.
Second, we studied the two eye-tracking metrics - i.e., saccade frequency and fixation duration - independently. However, these metrics, along with additional metrics such as pupil diameter, could be related to each other and may represent latent constructs that may not be sufficiently captured by using these metrics independently. Therefore, future steps will include analysing and quantifying the relationship between saccade frequency, fixation duration, and pupil diameter across the groups and types of tasks to better understand how eye-tracking metrics can serve as a method of understanding design cognition. Such an analysis combined with a qualitative examination of fixation points could explain differences in eye-tracking metrics from an attentional perspective. Furthermore, such multi-metric analyses could help understand the role of cognitive load, arousal, and fatigue.
Finally, future studies should consider factors that may reduce extraneous and confounding variables, such as fatigue. For instance, individuals with ADHD are also likely to experience fatigue and cognitive overload (Rogers et al., 2017), making counterbalancing the tasks especially important in reducing the

effects of fatigue on just one of the tasks. Verbal fluency assessments, such as the one used in the study, can lead to increased cortisol levels which would heighten anxiety (Walter & Bex, 2021) for future tasks. To reduce fatigue, future studies should also consider collecting data at a similar time each day and using sleep deprivation as exclusion criteria. Similarly, information regarding ADHD diagnosis was collected as a self-reported formal diagnosis. Participants without a formal diagnosis but who believed they may have ADHD were excluded from the study. Future work could verify their diagnoses using some form of non-clinical reporting of common symptoms.

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