How is Daylight Saving Time still a thing?: Disruptions from Daylight Saving Time transitions
lead to cognitive performance deficits

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Abstract

Visual search, looking for targets among distractors, underlies many critical professions and must often be performed optimally regardless of the time of day, week, or year. However, external events can disrupt the ability to perform. The current study examined one such specific event: Daylight Saving Time (DST) transitions—when the clock shifts forward or backward by one hour. Performance on a visual search task was assessed using “big data” from the mobile app *Airport Scanner* (Kedlin Co.), wherein players serve as airport security screeners searching for prohibited items among allowed items. Performance was compared between individuals who played a specific level during the week leading up to a DST transition (pre-DST transition) and those who played that same level during the week following a transition (post-DST transition). Analyses of data gathered over seven years revealed that, relative to the pre-DST group, the post-DST group was significantly slower, less likely to complete the level, more likely to fail due to running out of time, and had more false alarms. A control set of data (between individuals who played the level before or after a Sunday *without* a DST transition) revealed no significant differences. These results suggest that even minor, one-hour time shifts can create problems as they can adversely affect cognitive functioning; when an entire workforce simultaneously undergoes a sudden time shift (e.g., a DST transition), problems can potentially be exacerbated for the broader society. The current study lends support for existing efforts to end the archaic practice of DST.

Keywords: Daylight Saving Time, circadian rhythm, circadian disruption, big data, visual search, cognition

Significance Statement

Transitions to and from Daylight Saving Time (DST)—the twice-yearly practice of advancing or delaying the clock by one hour—is observed in over one-third of the nations worldwide, affecting billions of people. However, there is ample evidence that the circadian disruption caused by these one-hour time shifts might do more harm than good; as a result, there have been countless efforts to revise or eliminate the biannual time shifts. To date, much of the circadian disruption work has focused on the implications that DST transitions have on human health, behavior, the environment, and the economy, but it remains unclear how human cognitive functioning might also be affected by the circadian disruptions arising from these sudden time shifts. The current study leveraged a massive dataset to assess how visual search (looking for targets among distractors) competency varies as a function of time since a DST transition. Those who searched during the week after DST transitions were slower and had more false alarms than those who searched during the week prior to DST transitions. Importantly, control analyses showed that these deficits were not observed between those who searched the week before or after a Sunday without a time change. This project helps to establish that DST transitions can impact cognitive functioning, and it lends support to the growing efforts to end the practice of DST.

Introduction

In March 2015, on his talk show “Last Week Tonight,” John Oliver discussed Daylight Saving Time (DST) and asked a simple but poignant question—“how is this still a thing?” (LastWeekTonight, 2015). The concept of DST—advancing the clock by one hour for a portion of the calendar year—was first introduced (at a national level) in Germany during World War I as a temporary measure to extend the number of daylight hours and conserve fuel used for electricity (Buckle & Hocken, n.d.). The practice quickly spread, being adopted throughout Europe, North America, and beyond. Over a dozen countries were early adopters of DST (webexhibits.org, 2020), while there are currently 70 countries observing it (Harrison, 2013). Needless to say, this practice that was once intended to be a temporary step to save on energy costs in war time has become rather widespread and permanent.

While DST is now commonplace in many societies, there are questions about its utility today. For example, a century ago, DST *did* in fact conserve energy but now it is not so clear. Studies of some locations have shown evidence that DST reduced electricity consumption (e.g., Norway and Sweden: Mirza & Bergland, 2011; Ontario, Canada: Rivers, 2018), but others have seen no such benefits (e.g., Australia: Kellogg & Wolff, 2008). Perhaps not so surprisingly, the rampant use of modern technologies has led to *increased* energy consumption (and thus increased carbon dioxide emissions) during DST (e.g., Argentina: Hancevic & Margulis, 2016; Indiana: Kotchen & Grant, 2011). In the same vein, the evidence is equivocal on whether DST has broader impacts on society beyond energy savings. While there is work suggesting DST reduces rates of crime (Doleac & Sanders, 2015), seasonal depression (Hansen et al., 2017), and physical inactivity among children (Goodman et al., 2014), such benefits may be overshadowed by the costs that come along with DST and DST transitions.

Recent arguments have emerged suggesting that DST may have negative health, behavioral, and economic outcomes (e.g., Akarsu & Gümüsoğlu, 2019; Medina et al., 2015; Poteser & Moshhammer, 2020). From a health perspective, DST transitions (i.e., the time changes whereby the clock advances or goes back by one hour) have been implicated in causing increased numbers of emergency room visits (Ferrazzi et al., 2018) and an increased likelihood of miscarriage for women undergoing in vitro fertilization (Liu et al., 2017). In terms of behavioral implications, it has been shown that timing of sleep and activity does not readily adjust to a DST transition, particularly among late chronotypes (i.e., those who regularly stay up late) and high school students (Kantermann et al., 2007; Medina et al., 2015). Consequently, a wide range of behavioral outcomes have been found to be unfavorably impacted by DST transitions, including increased alcohol-related and non-alcohol-related fatal car accidents, increased workplace injuries, and increased patient-safety incidents (Barnes & Wagner, 2009; Fritz et al., 2020; Hicks et al., 1998; Kolla et al., 2020; Varughese & Allen, 2001). Finally, economic disadvantages of DST transitions include reduced labor productivity (Akarsu & Gümüsoğlu, 2019) and reduced stock market returns (Kamstra et al., 2000).

The negative impacts of DST transitions are consistent with physiological changes found from other forms of light-induced circadian disruptions in humans (e.g., social jetlag, longitudinal position within time zone, staying up late; Mah et al., 2018). Such other forms of circadian disruptions have been associated with adverse endocrine and cardiovascular risk profiles (Rutters et al., 2014), cancer incidence, cancer mortality, and life expectancy at birth (Borisenkov, 2011). Likewise, the observed DST transition effects are consistent with a large body of evidence showing negative impacts of circadian disruptions in non-human animals (e.g., Arble et al., 2010; Evans & Davidson, 2013; Rea et al., 2008).

Even though a one-hour time change seems relatively inconsequential, there are clear biological reasons to expect meaningful changes from a shift of such small magnitude. Unlike the gradual rotation (24 hours) and revolution (365 days) of the planet, DST transitions impose a *sudden* one-hour shift triggering an exogenous disturbance to our natural 24-hour biological clocks (i.e., circadian rhythm; Czeisler et al., 1999). This internal clock, subserved by the suprachiasmatic nucleus in the anterior region of the hypothalamus, regulates a variety of bodily processes (Albrecht, 2012; Labrecque & Cermakian, 2015; Roenneberg & Merrow, 2016) and relies heavily on retinal light inputs to self-sustain its oscillations (Ramkisoensing & Meijer, 2015). When a DST transition or any sudden shift in time (e.g., travel to a different time zone; Mah et al., 2018; Smith et al., 2013) occurs, patterns of environmental light exposure change, thus leading to asynchrony between the biological clock and the social clock (Kantermann et al., 2007; Roenneberg, Winnebeck, et al., 2019; Tarquini et al., 2019). This asynchrony subsequently leads to melatonin and cortisol imbalance which then disrupts circadian rhythm functioning (Altomonte, 2008; Borisenkov, 2011; Harrison, 2013; Karatsoreos et al., 2011; Tarquini et al., 2019). Dysfunction of the circadian cycle is a mechanism proposed to underlie the dire—and sometimes fatal—consequences of DST.

While the above discussion highlights an impressive and diligent effort by the academic community to delineate the benefits and drawbacks of DST (and circadian disruptions more generally), society at large seems to have come to a definitive conclusion—people simply do not like it. DST is often the target of mockery or ridicule (e.g., LastWeekTonight, 2015) and the twice-yearly transitions from Standard Time to DST and back are widely perceived as a nuisance causing unnecessary inconveniences to our everyday lives. As a result, there have been recent and ongoing calls from medical experts, parents, and lawmakers alike to eliminate DST altogether. For instance,

medical and sleep experts cite sleep loss and increased production of inflammatory markers (Harrison, 2013) and parents cite inconsistent sleep schedules and safety concerns when travelling to school in the dark (Achenbach, 2019; Bartky & Harrison, 1979) as reasons to stop observing DST. Meanwhile in the United States in the last five years, there have been over 200 bills and resolutions to end the twice-yearly practice of changing the clock (National Conference of State Legislatures, 2020). Similarly, the European Parliament recently voted in favor of abolishing DST (Buckle, n.d.).

To contribute to the existing literature on DST that has addressed how DST transitions impact physiological and health-related outcomes, the goal of the current paper was to assess potential impacts of DST on cognition. This is an important avenue to explore as it is possible that cognitive impairments could contribute to, or perhaps underlie, the litany of negative health consequences related to DST transitions. The current study examined the impact of DST transitions on performance in visual search—the ability to find targets among distractors. Visual search is a fundamental task that involves a range of cognitive abilities, including perception, attention, memory, and decision making (see Eckstein, 2011; Chan & Hayward, 2013; Nakayama & Martini, 2011 for reviews). Moreover, potential impacts of DST on visual search performance are important to understand as it is a skill that underlies several critical professions such as radiology, aviation security, and many military activities (e.g., Berbaum, 2012; Biggs et al., 2018; Wetter, 2013). Notably, many of these professions that rely on visual search require the workforce to perform optimally at all times—even in the days following a DST transition; thus, a significant decrease in cognitive performance following DST transitions could have meaningful impacts for society by informing future efforts to end DST.

Methods

To assess the impact of DST transitions on cognitive performance, the current study leveraged a massive dataset of visual search performance data gathered from millions of individuals over the course of seven years. This dataset afforded the ability to compare performance between the days leading up to a DST transition to the days following a DST transition. All aspects of the study design were pre-registered at <https://aspredicted.org/blind.php?x=zs9i5d>. The primary hypothesis was that search performance would be worse following a DST transition. Such a performance decrement is not expected during the period after a control Sunday (compared to the period before) wherein no time transition is observed.

Data acquisition. Data were anonymously collected from players of a publicly available mobile game, *Airport Scanner* (Kedlin Co., www.airportscannergame.com/airportscanner). Data were gathered by the game developer and then made available for research purposes. As of February 2021, the dataset contained data from approximately 15.5 million players¹ and 3.8 billion unique trials. This dataset has been used to explore a variety of questions (e.g., Biggs et al., 2014; Biggs et al., 2015; Ericson et al., 2017; Kramer et al., 2020; Mitroff & Biggs, 2014; Mitroff et al., 2015), and it provides a valuable tool for the current project as it includes data from before and after DST transitions across seven years. All study protocols were approved by the Institutional Review Board at The George Washington University.

Visual search task. The primary activity in *Airport Scanner* was a visual search task wherein players took on the role of an airport security screener and looked for illegal items (i.e., targets) among allowed items (i.e., distractors) in simulated luggage (Figure 1A). Bags moved

¹ The term “player” refers to a unique device ID, meaning that multiple individuals could have played the game on one device and/or that one individual could have played the game on multiple devices.

across the screen on a conveyor belt and players tapped on target items with their fingers while withholding taps on bags without a target (but could swipe the bag off screen to clear it more quickly). There was a 50% probability that each bag (i.e., trial) contained a target and bags could contain zero, one, or two targets. The nature of the game dynamics encouraged players to be both quick and accurate throughout the game as they could fail a level for either being too slow or missing too many targets. Players could quit/close the app at any time. In the game, players progress through a series of “airports” each containing multiple levels. The visual search data analyzed for the current study were taken from players’ first attempt at *Honolulu Day 1*—the first level of the first airport (which follows an initial tutorial phase that introduces the mechanics of the game). This level contains 24 trials and is relatively easy since it is early in the gameplay. The players’ first attempt at this level was chosen for analyses as it maximized the number of players while also equating experience and difficulty. However, since most players were quite accurate on target-present trials in this level, the hit rate measure of accuracy was close to ceiling. As a result, the primary dependent variable of interest here was response time on *single-target* trials. Since fewer than half of all players saw at least one dual-target trial in *Honolulu Day 1*, and analysis of dual-target response times are beyond the scope of interest for this project, all subsequent mentions of “response time” focus on *single-target* trials only.

Design. Visual search performance was examined for players who played *Honolulu Day 1* within a 14-day time window around either of the two DST transitions: phase advance (i.e., Springtime shift where an hour is lost) or phase delay (i.e., Autumntime shift where an hour is gained; Figure 1B) across seven years (2013-2019). Those who played in the seven days leading up to a phase change are referred to here as the pre-DST transition group, and those who played in

the seven days following/including a phase change are referred to as the post-DST transition group (Figure 1C).

Data were limited to the specific DST transition dates used by the United States and Canada (2nd Sunday of March (Figure 1C) and 1st Sunday of November) from 2013 to 2019, and, in conjunction, the data were limited to players from the five time zones that cover those two contiguous countries (Eastern, Central, Mountain, Pacific, Alaska). Further specification only included data from gameplay between 6:00:00 AM and 11:59:59 PM local time to limit data to prototypical awake hours. With these date, location, and time restrictions, the final sample included data from 79,249 players.

In line with the pre-registered plan, a control set of data was retrieved and analyzed from players who played *Honolulu Day 1* within a 14-day time window around the 3rd Sunday of September (wherein there is no phase change) from 2013-2019, yielding an additional 27,734 players. This Sunday was chosen as a control date as it is not typically near a national holiday in Canada or the United States and to focus on a “normal” two-week period. It was dummy coded as the day with a “critical time change” and players whose gameplay fell in the first seven days were the “pre-group” whereas players whose gameplay fell in the last seven days were part of the “post-group.” These data had the same time and location restrictions as those described above.

The game developer (Kedlin Co.) provided the research team with anonymous data that did not contain any identifiable markers; data were tagged by time zone, but no other location-based information was available. As such, the inclusion of data from the five relevant time zones included both players who underwent a DST transition (e.g., the majority of the players who were located in Canada or the United States) as well as others who did not (e.g., players from specific areas that do not observe DST such as the state of Arizona and players from countries that observe

DST on different dates such as Mexico). To estimate the percentage of the data that came from players who underwent a DST transition, independent data were obtained from Kedlin Co. that contained the number of devices active on a given day from [a] the United States, [b] Canada, and [c] Mexico & Latin America. For the calendar days used in the current analyses, approximately 90% of the data were from the United States and Canada whereas approximately 10% were from Mexico & Latin America (data from other areas of the world were not considered for these purposes). These calculations suggest the current analyses were relatively conservative as they contained approximately 10% noise (i.e., ~10% of the players in the post-DST transition group did not undergo a DST transition on the Sunday prior).

Figure 1. [A] Sample visual search trials from *Honolulu Day 1* of Airport Scanner with either a single-target present (top; from left to right: bomb, crossbow, hammer) or no target (bottom). The saliency and number of targets/distractors varied across bags. Images are presented with permission from Kedlin Co. [B] Schematic of phase shift directions that occur on the second Sunday in March (advance; left) and first Sunday in November (delay; right). [C] Example of how players were categorized into participant groups; those who played *Honolulu Day 1* the week prior to a critical Sunday (blue) were grouped into the “pre-DST transition group” and those who played the week following a critical Sunday (orange) were grouped into the “post-DST transition group.”

Results

Analyses were pre-registered at <https://aspredicted.org/blind.php?x=zs9i5d>. The primary dependent variable of interest was response time—average time to correctly tap on a target on single-target trials. This particular variable was *a priori* selected given it was predicted that response time would have sufficient between-subject variability making it a potentially meaningful individual difference measure (as opposed to accuracy, that was *a priori* predicted to be near ceiling with limited variability). The data bore out these predictions as the response time data were relatively variable ($\bar{x} = 2273$ ms, $s_x = 440$ ms) while the accuracy data were not ($\bar{x} = 94.67\%$, $s_x = 9.88\%$). To be clear, the suggestion here is not that DST transitions are more or less likely to impact the speed of response over any other measure, such as accuracy, but rather that in this particular experimental paradigm the response time measure had usable variability to make it a viable measure of interest. Secondary, exploratory analyses assessed additional behavioral parameters, such as false alarm rate (rate of incorrectly tapping on a bag or distractor item on target-absent trials), completion rate (proportion of players who completed all 24 trials of the level), and timeout rate (proportion of players who fail the level due to running out of time). For each variable of interest, performance was compared between the pre-DST transition group and the post-DST transition group. As delineated in the pre-registration plans, players who completed fewer than five trials of the level were excluded from all analyses.

Response time. Response time data from single-target trials were analyzed via a 2x2 between-subjects ANOVA with participant group (pre-DST transition group, post-DST transition group) and phase shift direction (phase advance in Spring, phase delay in Autumn) as the two factors. Of primary interest was the main effect of participant group, as a significant effect of group would suggest that response times were systematically different for data before and after the DST

transitions. Of secondary interest was the interaction term whereby a significant interaction would suggest that response times were differentially affected by DST transitions depending on whether an hour was lost or gained. The ANOVA produced a significant main effect of participant group ($F(1, 832241) = 4.246, p = 0.039, \eta^2 = 0.000$), a significant main effect of phase shift direction ($F(1, 2.38e^7) = 121.424, p < 0.001, \eta^2 = 0.002$), and no significant interaction ($F(1, 162186) = 0.827, p = 0.363, \eta^2 = 0.000$; Figure 2). As predicted, the significant main effect of participant group was such that response times were slower after a DST transition than before (i.e., an effect of the DST transition that slowed responses times). The significant main effect of phase shift direction was such that the response times were slower around a phase advance (Spring) than a phase delay (Autumn). Given this seasonal effect was not a predicted outcome and that it does not have a clear theoretical or mechanistic connection to the primary scope of the current project, no further emphasis is placed on this effect. The lack of a significant interaction between the participant groups and the phase shift direction suggests that the magnitude of the effect of DST transitions did not significantly vary from a phase advance (in Spring) to a phase delay (in Autumn), and thus it was not warranted to conduct subsequent post-hoc analyses that specifically focused on phase advance versus phase delay effects. That said, this is a common question of interest (i.e., are DST transitions worse when the clock advances an hour, rather than falls back an hour), so further information is available in Appendix A for those who are interested.

Response time data before and after a DST transition

Figure 2. Response time data on single-target trials for gameplay prior to a DST change (blue) and after a DST change (orange) for phase advances (left) and phase delays (right). Means (and standard deviations) provided in the corresponding columns. Error bars depict standard error of the mean (SEM). The ANOVA statistics in bold depict which groups demonstrated a significantly slower response time.

To ensure that the reported findings were not due to some other external factor (e.g., performance gradually getting worse over the course of a calendar year), a control set of data was analyzed that was centered around the 3rd Sunday of September (a date that does not involve a DST transition). The main experimental (i.e., DST transition (collapsed across phase advance and phase delay)) and control (i.e., no DST transition) response time data were entered into an omnibus 2x2 ANOVA with participant group (pre-group, post-group) and the presence of a DST transition (DST transition, no DST transition) as the two factors. Of primary interest was the interaction term, as a significant interaction would suggest that response times varied by group depending on whether or not game play occurred around a DST transition. The ANOVA revealed no significant main effect of participant group ($F(1, 901) = 0.005, p = 0.946, \eta^2 = 0.000$), a significant main effect

of the presence of a DST transition ($F(1, 1.11e^7) = 57.543, p < 0.001, \eta^2 = 0.001$) such that response times were slower around a DST transition, and a significant interaction ($F(1, 1.46e^6) = 7.531, p = 0.006, \eta^2 = 0.000$; Figure 3). Crucially, post-hoc t -tests between the pre- and post-groups demonstrated slower response times in the post-group around a DST transition ($t(75934) = 2.570, p = 0.010, d = 0.019$) but not in the absence of a DST transition ($t(27703) = -1.673, p = 0.094, d = -0.020$; Figure 3). The average difference in response times between the pre-DST transition group ($\bar{x} = 2276$ ms, $s_x = 441$ ms) and post-DST transition group ($\bar{x} = 2284$ ms, $s_x = 445$ ms) around a DST transition was 8 milliseconds ($\sim 0.35\%$ change).

Prior work has provided evidence that detrimental effects of DST transitions can linger for a few days (e.g., Barnes & Wagner, 2009) up to 19 weeks (e.g., Ferrazzi et al., 2018). As such, an assessment of how long the visual search deficits might persist after a DST transition was part of the pre-registered analysis plan for the current project. An omnibus 2×7 ANOVA with factors of participant group (pre-DST transition, post-DST transition) and day-of-week (Sunday through Saturday) revealed no significant interaction ($F(6, 2.05e^6) = 1.740, p = 0.108, \eta^2 = 0.000$), suggesting that the differences between pre- and post-DST transition performance was not significantly different based on days passed since the transition. Accordingly, no further analyses were warranted to examine how long the visual search deficits might persist.

Response time data for Experimental (DST transition) and Control (no DST transition) groups

Figure 3. Response time data on single-target trials for gameplay prior to a critical Sunday (blue) and after a critical Sunday (orange) for when a phase change actually occurred (left, filled bars) and for the no phase change control with no DST transition (right, unfilled bars). Means (and standard deviations) provided in the corresponding columns. Error bars depict SEM. The ANOVA statistics in bold depict which groups demonstrated a significantly slower response time.

Secondary variables of interest. In addition to the primary, pre-registered dependent variable of interest (response time), several exploratory pre-registered analyses were also conducted. Differences between groups were assessed on hit rate (rate of correctly tapping on a target on target-present trials), miss rate (rate of not tapping on/finding a target *and* not suspecting a target-absent bag of containing a target), false alarm rate, time to clear a bag on target-absent trials, dual-target accuracy (accuracy on second targets given that a first target was found), and proportion of players who [1] completed the level, [2] failed the level due to running out of time, [3] failed the level due to missing targets on three different trials, and [4] quit the level or closed

the app. Of these exploratory measures, false alarm rate, completion rate, and failure due to running out of time demonstrated a significant difference between pre- and post-DST transition groups and the corresponding results are reported below.

Additional 2x2 ANOVAs with factors of participant group (pre-DST transition, post-DST transition) and phase shift direction (phase advance, phase delay) demonstrated that false alarm rate on target-absent trials, the proportion of players who completed the level, and the proportion of players who failed the level due to running out of time, were affected by DST transitions (Figure 4). For false alarm rate, there was a significant main effect of participant group ($F(1, 1050) = 6.230, p = 0.013, \eta^2 = 0.000$) such that there were more errors after a DST transition, a main effect of phase shift direction ($F(1, 14236) = 84.410, p < 0.001, \eta^2 = 0.001$) such that there were more errors around a phase advance, and no significant interaction ($F(1, 203) = 1.200, p = 0.273, \eta^2 = 0.006$; Figure 4A). For proportion completed, there was a significant main effect of participant group ($F(1, 0.063) = 4.692, p = 0.030, \eta^2 = 0.000$) such that completion rates were lower after a DST transition, a main effect of phase shift direction ($F(1, 0.698) = 51.990, p < 0.001, \eta^2 = 0.001$) such that completion rates were lower around a phase advance, and no significant interaction ($F(1, 0.004) = 0.319, p = 0.572, \eta^2 = 0.000$; Figure 4B). Finally, for proportion of level failures due to timeouts, there was a significant main effect of participant group ($F(1, 0.063) = 7.651, p = 0.006, \eta^2 = 0.000$) such that timeout rates were greater after a DST transition, a main effect of phase shift direction ($F(1, 0.305) = 36.998, p < 0.001, \eta^2 = 0.000$) such that timeout rates were greater around a phase advance, and no significant interaction ($F(1, 0.002) = 0.291, p = 0.590, \eta^2 = 0.000$; Figure 4C). Further examination on how the effect of DST transitions on these measures may vary from phase advance to phase delay can be found in Appendix A.

Figure 4. Data for [A] false alarm rates on target-absent trials, [B] proportion who completed the game level, and [C] proportion who failed the level due to running out of time for gameplay prior to a DST change (blue) and after a DST change (orange) for phase advances (left columns of each figure) and phase delays (right columns of each figure). Means (and standard deviations) provided in the corresponding columns. Error bars depict SEM.

Control analyses, analogous to that conducted for response time, all revealed significant interactions between participant groups and the presence of a DST transition (all $ps < 0.030$). Subsequent post-hoc t -tests demonstrated a difference between groups (whereby performance was worse for the post-group) during a DST transition (all $ps < 0.020$) but not during a control period (all $ps > 0.090$). Omnibus 2x7 ANOVAs with factors of participant group (pre-DST transition, post-DST transition) and day-of-week (Sunday through Saturday), analogous to that conducted for response time, revealed no significant interactions (all $ps > 0.130$), again suggesting that the differences between pre- and post-DST transition performance was not significantly different based on days passed since the transition.

Discussion

The current study explored a fairly simple and straightforward question—is cognitive performance impaired by Daylight Saving Time (DST) transitions? The key finding was that response time in a visual search task—a task that involves a number of cognitive components

(attention, perception, memory, decision making, etc.) and is socially relevant as it underlies many critical professions (e.g., aviation security, radiology)—was significantly worse following a DST transition. Two participant groups partook in the same complex visual search task with the sole difference being the day in which they happened to participate: either during the week before or the week after a DST transition. Those who participated after a DST transition were significantly slower on average. Additional, pre-registered analyses revealed that the post-DST transition group was also more likely to false alarm on target-absent trials, less likely to complete the level, and more likely to fail specifically due to running out of time. Consistent with some of the prior literature (e.g., Hicks et al., 1998; Varughese & Allen, 2001), there were no significant differences based on whether the DST transition was a phase advance (lose an hour in the Spring) or a phase delay (gain an hour in the Autumn; see more in Appendix A). Collectively, these results suggest that cognitive performance suffers following a one-hour time shift that creates a mismatch between an individual's internal clock and the social time.

While the current study primarily focused on the dependent variable of response time, this does not necessarily mean that similar effects would or would not be found for other outcome measures, such as accuracy. Specifically, the focus on response time was pragmatic as accuracy on the early levels of *Airport Scanner* were close to ceiling, leaving little to no room for variation. Accordingly, it is not the case that one should conclude from the current results that DST transitions do not impact accuracy, but rather it was simply not an aspect informed by the current work. That said, the current findings did show that the correct rejection rate on target-absent trials (i.e., the ability to correctly report no target was present; Figure 4A) was significantly impaired following a DST transition. While this measure is related to overall accuracy, it is unclear how the

effects of DST transitions are mediated by other factors such as vigilance, impulsivity, or cognitive control (Craig & Condon, 1985).

A “big data” approach was used here to examine naturalistic behavior (performance in a mobile gaming app) as a factor of when that behavior was performed. This afforded the opportunity to have sufficient power to address a potentially subtle effect, but it also came with some drawbacks. For example, the current results are likely conservative estimates given that roughly 10% of the data came from players located in states or countries that did not observe DST or did not have DST transitions on the study dates. Thus, the true magnitude of the effect of DST transitions on visual search competency is likely (approximately 10%) higher than what is reported here.

With this conservative estimate in mind, however, a fair question is just how meaningful are the present results—is the observed small slowdown an impactful difference? The primary response time effect was an 8-millisecond slowdown for the post-DST group compared to the pre-DST group (Figure 3), which equated to roughly 0.35% slower. This difference, while seemingly small, is actually quite meaningful and can have severe implications for everyday life. From a population-level consideration, even a small slowdown can have a massive effect if the slowdown is systematic for the population (i.e., if most individuals suffer from the same slowdown at the same time, it can impact the society at large). For instance, in a typical week the US Transportation Security Administration screens about 12 million passengers at airports around the United States ([tsa.gov](https://www.tsa.gov), 2021). If, on average, it takes 30 minutes per passenger to pass through the security checkpoint, and after a DST transition the screening process is 0.35% slower than average (which could arise from any individual in the process being slower, whether that be the screening officer, the officer checking passenger IDs, the officer conducting pat-downs, the passenger, etc.), the

process will take an additional 6.3 seconds per passenger (0.35% of 30 minutes $\approx$ 0.105 minutes or 6.3 seconds). This additional 6.3 seconds per passenger equates to more than 2.39 years of accumulated time lost (for 12 million passengers) over the course of *each* week following a DST transition (Table 1). That is, Americans waste an estimated 2.39 years of their collective time waiting in line at the airport *two times every year*! Following this same logic, if society generally operates at a rate that is 0.35% slower than average for the week following each DST transition, then most every activity—from the mundane to the critical—should suffer from disturbingly high accumulated collective time lost. For example, grocery store checkout lanes, fast food drive thru lines, and emergency room wait times should have accumulated time lost over the week after a DST transition that equate to more than 7.73 years (Mitova, 2020), 3.42 years (mcdonalds.com, 2020; wbur.org, 2019), and 259.8 days (Blakemore, 2020) respectively (Table 1). The main point here is that in certain scenarios such a slowdown can have large scale impacts for society as a collective group. From an individual-level consideration, a slowdown of just 8 milliseconds can still have critical implications, particularly for tasks that require millisecond-level precision. A soldier being ever so slightly slower to fire at an enemy combatant, a driver being just slightly slower to hit the brakes, and a surgeon being slightly “off” can all mean the difference between life and death.

Table 1. Accumulated time lost following a single DST transition at the society level; the cumulative impact of a 0.35% slowdown.

	Estimated number of cases/week	Average wait time/case	0.35% slower/case (seconds)	Accumulated time lost (time lost per case * # of cases)		
				Hours	Days	Years
US Transportation Security Administration	12,000,000 passengers ¹	30 minutes	6.30 seconds	21,000	875	2.39
US grocery stores	226,000,000 shoppers ²	5 minutes	1.08 seconds	67,800	2,825	7.73
Fast food drive thrus	112,500,000 diners ^{3,4}	4.5 minutes ⁴	0.96 seconds	30,000	1,250	3.42
Emergency rooms	2,673,000 patients ⁵	40 minutes ⁶	8.40 seconds	6,327	260	0.71

¹[tsa.gov](https://www.tsa.gov) (2021); ²Mitova (2020); ³[mcdonalds.com](https://www.mcdonalds.com) (2020); ⁴[wbur.org](https://www.wbur.org) (2019); ⁵[cdc.gov](https://www.cdc.gov) (2017); ⁶Blakemore (2020)

It is interesting to consider the role that DST-driven cognitive impairments may play in the litany of health and safety impairments discussed in the introduction. It has been well-established that the various impairments following a DST transition are due to an individual's circadian clock being entrained by the sun rather than socialized time (Roenneberg et al., 2007). DST transitions knock this entrainment out of sync (i.e., circadian disruption) and give way to a variety of biological- and health-related catastrophes (e.g., Barnes & Wagner, 2009; Hicks et al., 1998; Liu et al., 2017; Manfredini et al., 2019). On one hand, it is possible that this asynchrony separately gives rise to the cognitive impairments reported here. On the other hand, it may be the case that cognitive impairments mediate the effect that circadian disruptions have on various health outcomes after a DST transition (e.g., Kolla et al., 2020). While the current findings do not speak directly to the mechanisms that underlie the negative health consequences of DST transitions, it is an important for future work on DST transitions to consider the role that cognitive impairments play on post-DST transition behaviors.

A large body of literature has demonstrated the impact that DST transitions have on health, behavior, and the economy (e.g., Akarsu & Gümüsoğlu, 2019; Medina et al., 2015; Poteser & Moshhammer, 2020)—and the current study adds complementary data demonstrating a negative impact on cognitive functioning. While these efforts collectively support the notion that the twice-yearly DST transitions should be re-evaluated, and probably eliminated, a key open issue remains. If the transitions are eliminated, a debate would ensue about whether to maintain year-round Standard Time (i.e., what is currently observed from November through March in the US) or year-round DST (i.e., what is currently observed from March through November in the US). While sleep and circadian experts have suggested that it is better to have permanent Standard Time (Rishi et al., 2020; Roenneberg, Wirz-Justice, et al., 2019), some lawmakers prefer to have year-round DST (Gray & Jenkins, 2019). More recently, due to the COVID-19 pandemic there was a push to extend Daylight Saving Time (and thus eliminate the Autumnal DST transition) in 2020 to avoid further disruptions to everyday life ([rubio.senate.gov](https://www.rubio.senate.gov)). Further research will be needed to examine how visual search competency and the variety of other factors fare as a function of Standard Time or DST to provide support for the permanent use of one over the other.

Conclusion

The present work explored how a DST transition—the phase advance (lose an hour) that occurs in the Spring or the phase delay (gain an hour) that occurs in the Autumn—could impact cognitive function and found that performance was significantly worse after a transition compared to before. The reported findings suggest that DST transitions may pose a threat to cognitive functioning as evidenced by visual search deficits. The data presented here lend further support to the many existing efforts to end the artificial and archaic practice of DST altogether. In sum, John Oliver put it best: “Daylight Saving Time—How is this still a thing?” (LastWeekTonight, 2015).

Declarations

- **Abbreviations**

DST: Daylight Saving Time

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- **Authors' contributions**

S.N., A.Y., and S.M. all contributed to the theoretical motivation, study design, analysis plan, and writing of the paper. S.N. analyzed the data and drafted the paper. A.Y. and S.M. provided guidance in all stages. All authors read and approved the final version.

- **Ethics approval and consent to participate**

This research was approved by The George Washington University Office of Human Research-International Review Board.

- **Consent for publication**

Not applicable.

- **Competing interests**

The authors declare that there are no competing interests.

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- **Availability of data and materials**

All data are available upon reasonable requests made to the corresponding author at

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- **Open practices statement**

All aspects of the study design and analysis were pre-registered at

<https://aspredicted.org/blind.php?x=zs9i5d>.

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(Appendix follows)

Appendix A. DST transitions during a phase advance versus a phase delay

Each calendar year there are two DST transitions—a phase advance in Springtime (lose an hour) and phase delay in Autumntime (gain an hour). Prior work has produced mixed findings on whether the phase direction is a meaningful factor, by which some outcomes are only impacted after a phase advance (Barnes & Wagner, 2009; Kantermann et al., 2007) and others are impacted after both a phase advance and a phase delay (Hicks et al., 1998). Since the current dataset did not demonstrate a significant interaction between participant group (pre-DST transition group, post-DST transition group) and phase shift direction (phase advance, phase delay) for any behavioral measure, post-hoc tests to assess whether the effect of participant group was present during one, both, or neither type of phase change was not statistically warranted. However, whether the effect of DST transition was consistent across phase advances *and* phase delays or was only present after a phase advance is a question of potential interest to the community of scientists and legislators who wish to end DST altogether. As such, the data are presented here for those who are curious—but should be taken with the caveat that these are post-hoc, exploratory analyses.

The four behavioral measures in the main text (response time, false alarm rate, completion rate, time out rate) all demonstrated a main effect of phase shift direction such that performance was better around one phase shift direction than the other (i.e., performance was significantly better around either a phase advance or a phase delay). Post-hoc *t*-tests for all four measures showed that the effect of DST transitions was present during either the phase advance or the phase delay, but not during both types of phase transitions. Response times were slower in the post-DST transition group during a phase advance ($t(42599) = 2.245, p = 0.025, d = 0.022$) but not during a phase delay ($t(33337) = 0.767, p = 0.443, d = 0.007$). False alarm rates were higher in the post-DST transition group during a phase delay ($t(45889) = 1.080, p = 0.280, d = 0.027$) but not during a phase advance

($t(33357) = 2.360, p = 0.018, d = 0.010$). Completion rates were lower in the post-DST transition group during a phase advance ($t(45891) = -2.110, p = 0.035, d = -0.016$) but not during a phase delay ($t(33358) = -1.050, p = 0.293, d = -0.020$). Finally, timeout rates were higher in the post-DST transition group during a phase delay ($t(45891) = 1.720, p = 0.086, d = 0.028$) but not during a phase advance ($t(33358) = 2.170, p = 0.030, d = 0.015$).

In sum, performance was significantly worse for the post-DST transition group during the *phase advance* for response time and completion rate and during the *phase delay* for false alarm rate and timeout rate. These data do not reveal a consistent pattern to elucidate whether visual search impairments are present only after a phase advance or phase delay. Conclusions should be tempered given that these are post-hoc, exploratory analyses and since the groups of players across the two phase shift directions were not randomly sampled.