Video Game Play as a Fatigue Countermeasure in Air Traffic Controllers

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BACKGROUND: Extensive research has demonstrated that shift-work and time of day affect one's ability to maintain alertness and vigilance. Research has also sought to determine ways to increase alertness and decrease the effects of fatigue in high vigilance environments, such as air traffic control. This study was designed to assess the effectiveness of video game play as a fatigue countermeasure in air traffic controllers.

METHODS: We tested 22 military air traffic controllers to ascertain whether video game play prior to time in the air traffic control room heightened their alertness during their shift. An oculometer, which is an objective measure of physiological arousal and visual alertness, was used to measure pupillary diameter, amplitude, latency, and velocity. Perceived alertness was assessed using the Stanford Sleepiness Scale. Over a 4-wk period, the air traffic controllers participated in a counterbalanced, within-subjects design study with experimental (video gaming prior to control room) and control (no video gaming prior to control) conditions.

RESULTS: We used a within-subjects, repeated measures MANOVA to compare differences in physiological and perceived alertness of individuals in the two conditions. Results indicated that video game play significantly increased physiological alertness in air traffic controllers, especially pupil diameter and velocity, and this effect was sustained for at least 30 min after they stopped playing. Perceived alertness was also increased by video game play.

DISCUSSION: These results indicate that video game play could be an effective fatigue countermeasure in high vigilance occupations such as air traffic control.

KEYWORDS: pupillometry, fatigue, alertness, video game play, shift-work.

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Rhythms in psychological and physiological functions are controlled by internal, circadian oscillators. These rhythms help prepare individuals to adapt to their environment. Under normal diurnal conditions, human circadian rhythms cycle at approximately 24 h, with a synchrony existing between the different bodily systems (i.e., body temperature, sleep/wake cycle, cortisol, testosterone, etc.). When constraints are placed upon the normal circadian cycle (e.g., through shift-work, extended hours, rotating schedules, and jet lag) a desynchronization of rhythms occurs. This desynchronization results in reduced alertness, reduced vigilance, decreased memory, decreased physical performance,[7] and increased susceptibility to fatigue and illness.[29]

We live in a society that has needs that must be met 24/7, and as a result we require people to work during times which are not optimal based on their rhythms. According to Hamermesh and Stancanelli,[9] a large percentage of workers in the United States work outside of the traditional 9 to 5, Monday through Friday work week. They found that 30% of U.S. workers work on weekends, 26.6% work night shifts, and more than 32% work more than 45 h per week. According to the National Institute on Occupational Safety and Health, 19% of working adults work more than 58 h per week.[17] These extended work hours and shifts that fall outside of the normal awakening period can influence individuals' health, performance, and fatigue.[7,29]

Shift work is associated with disrupted sleep and increased fatigue, especially in those who work the night shift.[14] Night shift can be particularly troublesome for employees, because night is the time that our bodies are naturally attuned to sleep. Shift workers often experience desynchronization in their

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sleep/wake cycle, which can lead to numerous problems on the job. Fatigue, lack of concentration, performance errors, reduced productivity, and accidents during shift work can be explained, in part, by disruptions to our body's internal biological clock.[7] Fatigue's role in human error is not to be underestimated. Dawson and Reid[4] demonstrated that fatigue's cognitive impairments are comparable to those produced by alcohol consumption, and our ability to recover from these mistakes is directly related to our level of fatigue.[27]

Fatigue affects everyone, but the demands placed upon individuals who are responsible for safety can be especially problematic. In air traffic controllers, fatigue is extremely detrimental, as it leads to decreases in reaction time and attention. Because air traffic control requires high levels of visual vigilance, it is especially susceptible to the effects of fatigue, since visual tracking performance decreases with fatigue.[22,28]

Fatigue is considered to be a huge factor in human error and performance; consequently, many measurement tools have been developed to assess fatigue. The vast majority of research conducted on fatigue has used subjective fatigue measurement scales, as these are easy to administer, require little time away from the job, and can be administered in the field. The most commonly used subjective assessments are the Fatigue Severity Scale, the Fatigue Subscale of the Visual Analog Scale (VAS-F), The Swedish Occupational Fatigue Inventory, the Multidimensional Fatigue Inventory, the Karolinska Sleepiness Scale, and the Stanford Sleepiness Scale. However, subjective measures of fatigue are, by their very nature, something that can be modified based on the user's perceptions and feelings at the time. Thus, they are not as valid a measure of physiological fatigue as other objective measures, such as measurement of pupil activity, which is a measure of underlying noradrenergic activity.

The noradrenergic system, specifically the locus ceruleus (LC), has been implicated in promoting wakefulness.[24] The LC promotes wakefulness by increasing other wakefulness-promoting areas in the hypothalamus and also by inhibiting factors that are sleep-promoting.[25] The alerting activity of the LC can be measured by assessing fluctuations in pupil diameter.[12] This change in pupil diameter (PD) is the result of the stimulation of the sympathetic branch of the Edinger Westphal (EW) nucleus of the oculomotor nerve (increased dilation), as well as the inhibition of the parasympathetic branch of the EW nucleus (decreased constriction).[25,31] Thus pupillary diameter is the result of the interplay of activity between both wakefulness and sleep promoting regions of the brain and sympathetic and parasympathetic activity.

Other pupillary responses to light, such as pupil movement amplitude, response latency, and velocity also demonstrate underlying noradrenergic system activity. These measurements of pupillary responses to light have been demonstrated to be valid, well-developed, and reliable physiological assessments of fatigue.[26] Pupillary oscillations reflect subjects' alertness,[3] and changes in pupil activity have been used as an objective assessment of alertness in sleep medicine and in psychopharmacological research.[24,31]

Pupillary responses to light, such as response latency, amplitude, and saccadic velocity (SV) have been used to identify mental fatigue.[18] Pupil response latency is the time from the onset of the stimulus to the onset of changes in diameter. Amplitude can refer to either maximal constriction following an alerting stimulus for a fixed point or to the amplitude of visual tracking between two stimuli. This paper investigates the latter pupillary amplitude (PA). A saccade is the movement of the pupil from one fixation point to another, and SV refers to the speed with which this occurs. Previous studies have demonstrated that pupillary latency,[8] amplitude, and SV[6] decrease with fatigue.[13] In addition to being affected by fatigue, SV has been shown to significantly decrease with time on task, as tested in air traffic controllers.[23] In addition, Morad demonstrated that pupillary activity (as assessed by diameter, amplitude, and SV) typically corresponds with subjective ratings of fatigue, as measured by the Stanford Sleepiness Scale.[16]

While fatigue and alertness can be affected by high vigilance tasks and shift-work, there are many ways to mitigate these effects. Fatigue countermeasures programs have been established in flight operations and military aviation to counteract the effects of fatigue, improve sleep, and reduce errors.[2] Techniques such as exercise, controlled activity breaks, strategic napping, and medication have been used to fight fatigue and maintain alertness in aviation settings. However, different task requirements, real-world demands, and individual differences can affect the measure to which each of these is effective in reducing fatigue.

One additional strategy to combat fatigue that is gaining popularity is the use of video games. Weaver demonstrated that actively participating in video game play increases physiological arousal.[30] Ivarsson et al. found that video game play increased physiological arousal, as measured by increased heart rate.[11] A study by Segal and Dietz demonstrated that the physiological arousal from playing video games is equivalent to mild intensity exercise.[21] Video game play can also delay sleep onset and decrease sleepiness.[5] In addition to physiological arousal, Mathiak and Weber used functional magnetic resonance imaging to show that video game playing heightened cognitive alertness, especially during violent scenes.[15] However, Weaver showed that video game play increased cognitive alertness (as measured by self report Stanford Sleepiness Scale), but not physiological alertness (as measured by heart rate).[30]

Given the problems associated with shift work and demands placed upon us by society, additional fatigue countermeasures that are versatile and convenient are needed. In addition, the countermeasures must be something that workers will comply with in order to increase efficacy. This study is designed to assess the use of video game play in air traffic controllers on both cognitive and physiological alertness. The first hypothesis of this study was that on days when video games were played, participants would show increased physiological and perceived alertness, as compared to days when video games were not played. Second, there was expected to be a time of day effect on alertness, with those tested in the morning expected to have increased alertness and decreased fatigue. Finally, it was hypothesized that duration of playing video games would impact alertness in a direct fashion, so that the more time spent playing video games the more alert the person would be.

METHODS

Subjects

This study was approved by the Weber State University Institutional Review Board, and written informed consent was obtained from all participants. All subjects were treated according to the ethical principles underlying human research participation protection as outlined by the American Psychological Association guidelines.[1]

There were 22 male air traffic controllers from the western United States who participated in this study. All were from the same squadron at a local military base. Members of this squadron worked a rapidly rotating shift schedule (day, evening), switching every week between the two. Participants ranged in age from 22–48, with a mean age of 34 (SD = 8). All participants were healthy, with corrected or uncorrected 20/20 vision. All participants had experience playing the video game Halo 3 (Bungie, Inc., Microsoft Studios, Redmond, WA) for a minimum of 6 mo prior to the start of the study.

Equipment

The PMI FIT Screener (oculometer) was used to objectively measure fatigue (PMI Incorporated, Rockville, MD). The oculometer has the ability to measure involuntary pupillary responses, which include saccadic pupil velocity (SV), diameter of pupil (PD), amplitude of pupil (PA), and pupil response latency to a mild flash of light. Goldich et al. found that all of these pupillary changes are affected by fatigue,[8] and Rowland, et al. showed that the use of the PMI FIT oculometer to measure pupillary response was a reliable indicator for assessing fatigue.[20]

To use the PMI FIT, participants looked into the eyepiece and had a series of dim lights displayed. The flashes of light were first stationery and then moving so that pupillary diameter in response to the presence (versus the absence) of light could be measured, as could the ability of the pupils to track the light. The display of lights lasted approximately 30 s. Pupillary responses to light were assessed through PD (change in the size of the pupil), SV (speed of pupil movement), PA (amplitude of pupil from a lateral gaze transfer between two lights presented asynchronously), and latency (how long it took for the pupil to move between two lights presented asynchronously).

Stanford Sleepiness Scale

The Stanford Sleepiness Scale (SSS) is a seven-step standardized subjective rating Likert scale for estimating sleepiness. The subject is asked to estimate their subjective level of sleepiness, with a score of 1 representing "Feeling active, vital, alert, or wide awake," and a score of 7 being, "No longer fighting sleep, sleep onset soon; having dream-like thoughts."[10] This measure has high convergent validity with other subjective sleepiness scales (POMS and VAS)[19] and is one of the most commonly used sleep scales in fatigue research.

Procedures

Prior to beginning data collection, subjects completed a demographics questionnaire, along with their informed consent, and they were assigned a number to be used with the oculometer. The air traffic controllers (ATCs) worked a rapidly rotating shift schedule, with day shifts one week and then night shifts the next week. All participants were tested on a Tuesday during both their night shift schedule and their day shift schedule across a 4-wk period during the summer months. Selection for order was done randomly based on subject number. The ATCs typically worked a schedule in which they spent 1 h in the control room and then 1 h outside of the control room on other tasks. During that time they were allowed to participate in activities to mitigate fatigue, such as exercise or video game play.

Participants were tested on either "play days" or "no play days." A "play day" was a day in which the participant was allowed to play the video game during the time in which they were out of the control room. All video game play and testing took place between 1600 and 1800 for night shift and between 0900 and 1100 for morning shift. Participants on "play days" would leave the control room, fulfill any work requirements, and then they would play Halo 3 for a minimum of 20 min (up to 60). Participants on "no play days" were asked to fulfill work requirements during this time and to refrain from playing video games during the day. In addition, all participants were asked to abstain from other fatigue countermeasures for 2 h prior to participating in the study, including the use of caffeine and exercise. No other fatigue countermeasures were controlled for.

Both groups had physiological and perceived fatigue measured prior to entering the control room after their 1 h break time. Physiological fatigue was measured using the oculometer (PMI FIT). Participants entered the code for the oculometer (the code was kept separate from other identifying data) and stood in front of the eyepiece. All participants' oculometer readings were taken from a standing position, since posture can affect alertness. They were asked to place their forehead on the forehead rest, and they were asked to look with one eye down the barrel projecting from the machine. Only one eye was used so that there was no discrepancy between pupillary responses. Participants were asked to use the same eye each time. Subjects were then asked to watch for a light stimulus that would be presented, followed by another stimulus. They were told to move their eyes so as to "follow" the light stimuli. The oculometer was then able to record PD, PV, PA, and latency to the movement.

Participants also completed the SSS prior to entering the control room. The combined time required for completion of the SSS and the oculometer test was approximately 2 min. Once the data were collected, the collection sheets were stored in a separate facility and the data were entered by someone not actively collecting data on site.

Statistical Analysis

Physiological and perceived fatigue were analyzed by time of day and by play day/no play day with descriptive statistics. A repeated measures multivariate analysis of variance (MANOVA) was used to assess the effects of time of day and video game play on the four measures of physiological fatigue and the one measure of perceived fatigue. A factorial, between subjects MANOVA was used to assess the effect of duration of playing and time since playing video games on the physiological fatigue measures. Tukey's LSD post hoc was used to determine between group differences for this MANOVA. Significance was defined as $P < 0.05$. SPSS version 24 was used to analyze the data.

RESULTS

There were 22 participants in this study, and each participant was tested twice on play days (AM and PM shifts) and twice on no play days (AM and PM shifts). Descriptive statistics for the physiological alertness (as measured by the pupilometer) and perceived alertness (as measured by the Stanford Sleepiness Scale) scores are shown in **Table I**. All scores that were outside of three standard deviation units from the mean were excluded from analysis, as were scores that had large Cook's distance values. Any missing data were not analyzed, but other data from those individuals were still used for within- and between-subjects analyses.

The effects of time of day (AM and PM) and video game play (play day/no play day) on the five measures of alertness were assessed using a repeated-measures 2 × 2 factorial multivariate analysis of variance (MANOVA). There was a main effect of time of day on physiological alertness, specifically pupillary diameter [$F(1,21) = 5.51$, $P < 0.05$, $\eta_p^2 = 0.11$], where pupil diameter was smaller in the AM as compared to the PM session. There was a significant main effect of video game play on physiological alertness [$F(1, 21) = 3.57$, $P < 0.01$, $\eta_p^2 = 0.20$], specifically on velocity and diameter. Those who played video games had a faster PV [$F(1,21)=6.73$, $P < 0.05$, $\eta_p^2 = 0.10$] and larger PD [$F(1,21) = 5.43$, $P < 0.05$, $\eta_p^2 = 0.03$] than those who did not play. There was a significant interaction between time of day and video game play on pupillary diameter, but not on other physiological measures. Playing video games had a much more alerting effect on pupil diameter during the morning shift than in the afternoon [$F(1,21) = 9.36$, $P < 0.01$, $\eta_p^2 = 0.24$]. Time of day and video game play's effects on pupillary diameter can be seen in **Fig. 1**. Video game play also significantly decreased the level of perceived fatigue [$F(1,20) = 4.10$, $P < 0.05$, $\eta_p^2 = 0.06$].

Descriptive statistics for the effect of time spent playing video games and time since playing video games are given in **Table II**. Originally the data were analyzed using a linear regression, given that time is a continuous variable. However, based on how the time series data clustered, both the time since playing video games and time spent playing video games were grouped into three categorical variables. Time since playing video games (VGs) was divided into three groups, 20 – 30 min since playing ($N = 10$), 40 – 50 min since playing ($N = 13$) and 60 min since playing ($N = 11$). Time spent playing VGs was divided into three groups, 30 min ($N = 11$), 45 min ($N = 12$), and 60 min ($N = 11$). While the interval sizes are not the same time-wise, they represent how people naturally played the video games, and the number of participants in each cluster were similar. All time slots fell within 2 min of these intervals.

A 3 × 3 factorial between subjects MANOVA was used to assess whether time spent playing (20 – 30 min, 40 – 50 min, 60 min) and time since playing (30 min, 45 min, 60 min) video games influenced alertness. There was no main effect of either variable on perceived alertness (SSS). Time since playing VGs had a significant main effect on physiological alertness [$F(8,44) = 3.044$, $P < 0.01$, $\eta_p^2 = 0.38$], specifically on diameter, latency, and velocity, as assessed by a Tukey's HSD post hoc analysis (Table II). Those who played video games had a significant increase in alerting effects that lasted at least 30 min, with only PD's effects lasting longer (45 min). Time spent playing VGs had a significant effect on physiological alertness [$F(8,44) = 2.37$, $P < 0.05$, $\eta_p^2 = 0.35$], specifically on diameter and latency, as assessed by a Tukey's HSD post hoc analysis (Table II). There was an interaction between time spent playing VGs and time since playing VGs [$F(12,62) = 1.97$, $P < 0.05$, $\eta_p^2 = 0.29$], but only for velocity. Those who played for less time and who went longer before testing had significantly slower velocity. Significant results can be found in Table II.

DISCUSSION

This study's results support the idea that video games can be used as a fatigue countermeasure. Results indicate that on days when the ATCs played video games, they felt more alert (as assessed by the SSS) and were physiologically more alert, specifically with regards to PD and PV. PD, which gets larger with increased alertness and noradrenergic activity, was significantly larger in those who played video games within an hour of testing as compared to those who did not, especially in the morning shift. Additionally, these effects lasted for at least 30 min, which is similar to the results found by Segal and Dietz.[21] PV was significantly faster in those who played video games within an hour of testing, regardless of how long it had been since they had been tested. The amount of time playing video games influenced alertness, specifically PD and PV. The longer the ATCs played (30, 45, or 60 min), the greater their PV and the larger their PD, with significant increases occurring between 60 min and the other two time periods.

Table I. Descriptive Statistics for Video Game Play and Time of Day Effects on Alertness.

	PLAY DAY				NO PLAY DAY			
	AM		PM		AM		PM	
ALERTNESS MEASURE	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
Diameter (PD) (mm)	4.39 (0.39)	0.39	4.58	0.39	4.01	0.5	4.33	0.53
Velocity (PV) (ms)	71.21 (2.97)	2.97	69.38	4.1	66.36	3.81	68.66	3.25
Amplitude (PA) (mm)	1.1 (0.19)	0.19	1.18	0.19	0.97	0.28	1.11	0.23
Latency (ms)	292.95 (16.21)	16.21	283.51	13.6	293.46	13.92	291.66	5.82
SSS	2.23 (0.92)	0.92	2.47	0.81	2.71	0.73	2.67	0.59

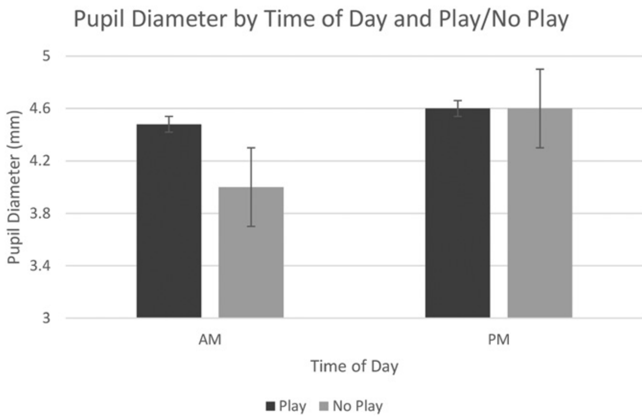

Fig. 1. Pupil diameter (PD) is shown by time of day and video game play/no play. Standard error bars are shown. Black bar = play; grey bar = no play.

Time of day had a significant effect on pupil diameter, but there was no other main effect for time of day. Playing video games increased pupil diameter in the morning shift more than in the evening shift, indicating that video games could have more of an alerting effect in the morning. In general, pupil diameter was smaller in the AM period, as compared to the PM testing time, regardless of play/no play status. This was contrary to our hypothesis, but it reflects the lack of conclusive support for circadian variation in pupil diameter.[31] Because we measured pupil responses between 0900 and 1100, and the work day started at 0700, it is possible that the duration of time at work had an effect on alertness. Those tested in the evening started their work day at 1600 and were tested between 1600 and 1800, thus limiting their cumulative work fatigue. Future studies should aim to control for this variability in time of testing.

Our study had the following limitations. First, we were constrained by the collection of data in a working air traffic control facility. We had no control over what activities the ATCs had experienced during their shift, including highly stressful activities or extreme boredom. The real-world site for data collection, and the way in which it corresponded to their typical daily activities lends external validity to the results, however, the lack of control threatens the internal validity. Future studies should attempt to replicate these findings in a more controlled situation.

One problem with using self-report data, such as the SSS, is that it is subjective. The mean scores on the SSS were always a score of two, which on the SSS corresponds to, "Functioning at high levels but not fully alert."[10] There was very little variability in these scores, although there was a significant decrease in score (i.e., increased alertness) on video game play days. The lack of variability, though, reflects the weakness of the score, as does the lack of correlation between SSS and any measure of physiological alertness (Pearson Correlation, $P > 0.05$). In addition, during the debriefing the participants suggested that they felt that they needed to say that they were alert, since they were on duty as air traffic controllers. These findings suggest that although the SSS may be a valid measure in some settings, it may be dependent upon the participants and their perceptions of what is considered acceptable for them in their current environment.

An additional limitation to the study was the ability of individuals to self-select into playing time periods. We allowed them to choose how long they wanted to play, so as not to disrupt their work requirements, but this created variability in the duration of play and the time since playing. Future studies should seek to control for this, although this did allow us to find that playing longer increases alertness (at least as measured by PD and PV) and that going longer without playing decreased alertness (as measured by PD, PV, and latency).

All participants in this study were male. There are currently no studies which assess how the effects of fatigue countermeasures might vary by gender, and this study continues that trend. Future studies should seek to identify if gender plays a role in recovery from fatigue.

Finally, the video game played, Halo 3, is a first-person shooter game that involves a team of players. It is possible that the social interaction was responsible for increasing alertness, and it is also possible that the nature of the game (violent) increased alertness. The process of actively participating in video games increases alertness, but perhaps the violence in video games also has an effect, as suggested by Mathiak and Weber.[15] Unlike Weaver,[30] we found that participating in video games increased both physiological and perceived alertness.

In conclusion, playing Halo 3 increased both physiological and perceived alertness in air traffic controllers. Multiple measures of alertness were used, and all but one showed an alerting effect from playing video games. The time of day that video games are played can also have an effect, with morning hours showing the strongest alerting response from video game play. The duration of video game play also had an effect on alertness, with longer duration resulting in increased alertness (within the time limits of this study). In addition, the alerting effects of playing video games lasted at least 30 min for some measures and longer for others. Given these findings, occupations with high vigilance requirements should consider video game play as a fatigue countermeasure option, especially for morning shifts.

Table II. Descriptive Statistics for Significant Effects of Time Spent Playing Video Games and Time Since Playing Video Games on Alertness.

	TIME SPENT PLAYING VGS			TIME SINCE PLAYING VGS		
ALERTNESS MEASURE	**20–30 min**	**40–50 min**	**60 min**	**30 min**	**45 min**	**60 min**
Diameter (PD) (mm)	4.49 (0.65)	4.48 (0.44)	4.8 (0.61)	4.63 (0.52)	4.6 (0.51)	
Amplitude (PA) (ms)				0.87 (0.16)		
Latency (ms)	289.8 (17.61)	289.4 (17.76)	286.7 (16.95)	272.99 (17.95)		

Means (SD) are shown for significant effects ($P < 0.05$), as compared to baseline measures.

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