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Evaluation of Flow Level through Pupil Size, Blink Rate and Blink Duration in Different Types of Smartphone Games

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Objective: This study examines the variables related to eye-activity which could calculate and quantify a user's flow level in three types of smartphone games.

Background: The issue of flow level or addiction related to digital media has mushroomed.

Method: A total of 25 subjects participated in this experiment. Three different types of smartphone games, utilizing the different flow experiences as defined by user questionnaire, were used for the experiments in this study. We measured the pupil size, blink rate and blink duration of the experiments' participants using an eye-tracking device called FaceLab. Deeper flow experiences corresponded with bigger pupil sizes.

Results: The results showed that pupil size and blink rate differed statistically by game type and game time. Puzzle game showed a higher pupil size than dot-to-dot and coloring games. Pupil size showed differed by game time ($p<0.05$) and large pupil size showed in the final period. Blink rate differed statistically by game time ($p<0.01$) except game type. Blink duration did not differ statistically by independent variables.

Conclusion: A quantitative study of the flow experience could help solve the problem in a measure of media flow level. Despite the spread of digital-media flow level, there have not been many studies on the actual effects of these flow level.

Application: To prevent this issue from getting too far out of hand, this study examines different types of mobile games addiction using variables of eye-activity: pupil size, blink rate, and blink duration.

Keywords: Flow level, Pupil size, Blink rate, Blink duration, Smartphone

1. Introduction

There has been a big boom in the use of digital media as a form of leisure, such as digital gaming, internet surfing, and various other digital applications. At the same time, the issue of addictions related to digital media (gaming, online gambling, online shopping and the internet over-usage) has mushroomed. Experts have posited that one of the factors involved in this type of addiction is the pattern of eye-flow (Gilleade et al., 2005). Moreover, due to the rising trend of addiction, the manipulation of eye-flow is becoming a negative concept and scientists have mostly focused on its deleterious applications (Gilleade et al., 2005; Chiang et al., 2011; Ryan et al., 2006). However, the eye-flow is a concept about state or attitude.

Though generic eye-flow manipulation is neither positive nor negative, the results of its application can take on a positive or negative slant. In the positive column, it can arouse practical creativity and flexibility of thought. It could help to raise work efficiency. It also encourages achievement. On the other hand, it can arouse obsession, lead to loss of control, stoke anxiety and lead to other negative behaviors associated with the physical, psychological or mental reliance stemming (Cooper and Michels, 1981; Sahin and Robinson, 1981; Glasser, 1985). Hoffman and Novak (1996), Novak et al. (1998, 2000) classified the psychological variables involved with the flow as the following: playfulness, skill, challenge, interactivity, focused attention, arousal, telepresence, time distortion, positive affect, exploratory behavior, and control, and described the relationship between these variables.

Novak et al. (2000) shows that of all the flow variables, the most dominant factors are telepresence and time distortion. The indirect variable is focused attention. Telepresence and time distortion are measured mainly by questionnaire (Cho et al., 2010; Lee, 2011). Attention has been measured by psychophysical methods such as monitoring brain activity, heart rates, gaze fixation, pupil response, and blink rate (Hackman and Guilford, 1936; Palmer et al., 1993; Graham, 1992). Moreover, Ravaja (2004) insisted that various physiological variables should be measured by analyzing the relationship between physical response and psychological reaction. Table 1 lists the psycho-physiological methods used in previous studies. The indicator of psychophysics has been used to measure attention and emotion, including various psychological processes such as stress or mental effort.

Table 1. Types of psychophysiological measures and sensitivity

Measure		Sensitivity	Study
Eye movement	Eye tracking	Visual attention	Wedel and Pieters (2008)
	Eye movement: Scanpath length and duration Convex hull area Spatial density Transition matrix Number of saccades Saccadic amplitude	Search behavior, interpretability	Goldberg and Kotval (1999)
Electromyography	Zygomaticus major (cheek) muscle activity ↑	Positive emotions	Bolls et al. (2001)
	Corrugator supercilii (brow) muscle activity ↑	Negative emotions Positive high-arousal emotions	Bolls et al. (2001) Jäncke et al. (1996)
	Orbicularis oculi (periocular) muscle activity ↑ (tonic)	Affective valence of the message	Bolls et al. (2001) Jäncke et al. (1996)
	Orbicularis oculi (periocular) muscle activity ↑ (blink reflex)	Affective valence of the message	Lang (1990)
Electrocardiogram	Tonic HR ↓	Increased attention; negative valence of stimuli	Bolls et al. (2001)
	Tonic HR ↑	Cognitive effort; stress; emotional arousal	Palomba et al. (2000)

Table 1. Types of psychophysiological measures and sensitivity (Continued)

Measure		Sensitivity	Study
Electrocardiogram	Phasic HR ↓	Orienting response (short-term change in attention)	Thorson and Lang (1992)
Electrodermal activity	Skin conductance level ↑	Information processing capacity to a stimulus	Hopkins and Fletcher (1994)
	Frequency of nonspecific skin conductance responses per minute ↑	Increased arousal	Grabe et al. (2000)
Brain activity	Brain electrical activity	The fast electrical response depends on highly memorable TV commercials	Rossiter et al. (2001)
	EEG	Brain activity by cognitive and emotional arousal	Krugman (1971)

↑ = increase, ↓ = decrease

According to a study by Cho and Shin (2002), people tend to blink less when they are playing computer games than they do when typing documents because of they devote higher concentration to it due to the pleasuring of playing the game. Kim et al. (2007) reported that states of flow can be different even for tasks performed on the same computer. The differences in flow depended on the type of task being performed. The blink rate depends on the level of flow, and low blink rate indicates a relatively high level of flow. Lee et al. (2012) found that a person's level of interest and the amount of concentration could be estimated by pupil size, and the greater the level of interest and concentration, the greater the pupil size. Thus, the aim of this study examines the variables of eye-activity which could calculate and quantify a user's flow level in three types of smartphone games and play time ranges by a psychophysiological method.

2. Methods

2.1 Subjects

A total of 25 subjects participated in this experiment. Participants in these experiments were selected if they had no vision problems in six months prior to the study and whose eyes were in good condition through the experiments. The visual acuity test was performed by all subjects using the visual acuity chart. Detailed subjects' information is in Table 2. The value for vision was measured by using the lower of the two eyes.

Table 2. Demographics of subjects

	Age (year)	Vision (corrected)	Weight (kg)	Height (cm)
Mean	28.54	1.34	71.54	168.54
SD	2.24	0.24	6.89	6.87

2.2 Apparatus

FaceLab 5 (Canberra, Australia, Seeingmachines Inc.) is an eye-tracking device that, along with its FaceLab 5.0.2 software, is used to measure pupil size, blink rate and blink duration (Figure 1 a). This tool engages in eye-tracking and measures pupil response as well as blink rate simultaneously. We used 60Hz sampling for data analyzing. To verify the quantitative data, we also used a flow state scale (FSS) questionnaire of the flow based on the index of the flow assembled by Jackson and Marsh (1996). A smartphone (I9100, 480 x 800 pixels) with a 4.3-inch screen were used to complete the experiments (Pantech Co., Ltd.) (Figure 1 b). Each participant was provided with a phone of the same screen size and brightness.

(a) (b)

Figure 1. Experiment apparatus (a: FaceLab; b: Smartphone)

2.3 Experimental design

The independent variables of a 2 × 3 within-subjects design were used with two levels of gameplay time ranges (initial and final) and three levels of game type (puzzle, dot-to-dot, and coloring) (Table 3). The initial range is defined as the first ten seconds of play time and the final range is the ten seconds before the end of the play. Testing each subject on all three kinds of digital games, each having different flow components. The games were classified according to the level of flow they required based on answers to questionnaires from the pilot test. The experimenter asked the subjects whether the style of the game was different. The pilot test was performed with 10 subjects. The dependent variables were the pupil size, blink rate, and blink duration.

Table 3. Types of mobile games

	Puzzle	Dot-to-dot	Coloring
Picture			

The data collected from the experiment concerning pupil size, blink rate, and blink duration were separated according to the type of game played and then averaged. The SAS 9.2 (SAS Institute Inc.) was used to perform the analyses of variance (ANOVA), followed by Tukey's Studentized Range (HSD) Test at a significance level of 0.01 and 0.05.

2.4 Signal processing

2.4.1 Pupil size

Average pupil size was recorded only when the participants' eyes were open; periods of blinking were not included in this average. In the software, the pupil was marked with a green circle. Then using the outline of this circle, the diameter of the pupil could be measured. When eyes were closed (due to blinking), it was not possible to measure the diameter, so that the sum of the pupil size were divided only by the frames that revealed the pupil.

2.4.2 Blink rate

The blink rate was measured per minute. Eye-blinking was defined as any closure of the eye that takes under the 0.35 seconds and over the 80 % of closure eyes consider as common eye-blinking. The blink rate is calculated by the following equation (1):

$$e_c = \frac{c_l e_l + c_r e_r}{c_l + c_r} \qquad \text{for } c_l + c_r > 0 \tag{1}$$

where,

e_l : Left eye closure value
e_r : Right eye closure value
e_c : Both eyes closure value
c_l : Confidence of left eye closure value
c_r : Confidence of right eye closure value

The left and right eye closure value was defined as the ratio of that eyelid closed, then calculated between 0, the value for completely opened eyes, and 1, the value for eyes that are entirely closed. Both left and right eyes closure values were summed, giving the eye-closure value a confidence value between 0 and 1.

2.4.3 Blink duration

Blink duration was calculated as the sum of common blinking time divided by the number of blinks. The common blinking definition was in the same way as blink duration with 60Hz sampling.

2.5 Procedure

To remove noise factors that may interfere with the flow, experiments were conducted in a quiet, isolated area. A curtain separated the participants from the experimenters. To provide similar illumination, all experiments were done in rooms with similar fluorescent lighting. A comfortable room temperature was also maintained throughout.

Before beginning, the experimenter explained to each participant the procedure and precautions and recorded demographic and visual information concerning each participant. The Experimenters gave the participants' goals to achieve during their play which were set slightly higher than what they achieved during their 15 minutes of practice play. We did not reveal to the participants how much time had passed during gameplay. The participants were instructed to play a game until told by the experimenter to stop.

The distance between the participants' eyes and the mobile device was kept at 30cm. To maintain this distance, participants were asked to use the chin rest placed on the desk. The experimenter then calibrated the eye tracker according to the position of the eyes after the participants' chin was firmly in place (Figure 2).

Figure 2. Experiment scene

After getting the participants into proper position, the experimenter explained how to play the games, and then the participants were given time to practice each of the games. When the participants were comfortable with playing a game, the experiment was begun. They were required to play each of the different games for ten minutes each. After each game, the participants answered the questionnaire on flow. To minimize eye fatigue, participants were given three minutes to rest between each phase of the experiment. Each game was played three times by each participant. However, to remove any carry-over effect, Latin square design was applied to determine the sequence in which the games would be played.

3. Result

Analyses of variance for flow state scale (FSS) ratings indicated that the main effects of game type ($p < 0.01$). According to the flow state scale (FSS) questionnaire (Wiebe et al., 2014), the puzzle game involved the highest value (Score: 4.12), then dot-to-dot (Score: 3.43) and coloring (Score: 2.98) (Figure 3).

Pupil size differed significantly by game type ($p<0.01$) and game time ($p<0.05$). Blink rate differed significantly by game time ($p<0.01$) except game type. Blink duration did not differ significantly by game type and game time. The interaction between game type and game time had no significant effects on the pupil size, blink rate, and blink duration (Table 4).

Puzzle game showed a higher pupil size than dot-to-dot and coloring games. The time progression of gameplay had a significance level of 10% with regards to pupil size. The blink frequency was also affected by the timing of gameplay. The puzzle game type was higher pupil size than other game types. The final period indicated high pupil size. Contrastively, blink rate indicated high value in the initial period (Figure 4).

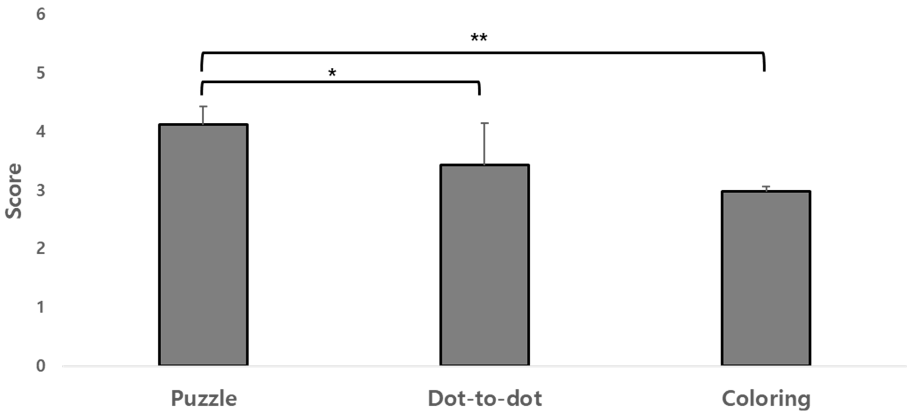
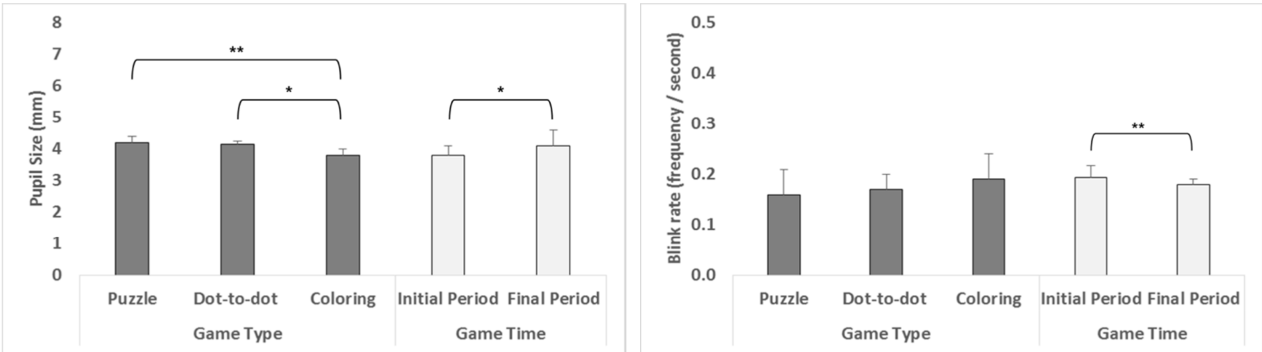


Figure 3. Comparison of the flow state scale (FSS) rating on game type (*$p<0.05$, **$p<0.01$)

Table 4. ANOVA assessing for pupil size, blink rate and maintenance time (F-value)

	Pupil size	Blink rate	Blink duration
Game type	14.31**	3.44[a]	3.43[a]
Game Time	5.55*	17.12**	4.76[a]
Game type × Game time	1.57[a]	2.90[a]	1.53[a]

*$p<0.05$, **$p<0.01$, [a] Not applicable



(a) Pupil size (b) Blink rate

Figure 4. Comparison of the pupil size, blink, and maintenance time of blink on game type and time (*$p<0.05$, **$p<0.01$)

4. Discussion

The puzzle game was rated higher flow level as defined by the FSS. The highest flow level game, the puzzle game, produced the biggest average pupil size of 4.11mm, then the dot-to-dot game with an average pupil size of 4.00mm, followed by the coloring game with an average pupil size of 3.75mm. The questionnaire of the FSS yielded the same order according to the flow measured by pupil size. The difference in pupil size measured for each type of game is an indicator of the participants' concentration level.

Concentration has a primary effect on flow experience, so the difference in pupil size can be used to identify the flow-level.

The pupil size varied depending on time progression. During the final part of the game, the pupil size was an average of 3.99mm, whereas, during the initial sequence of the game, the average pupil size was 3.91mm. A comparing these two game phases, the pupil size was 2.1% bigger during the final part of the game. These results show that the longer the game goes on, the flow level was higher, resulting in a larger pupil.

The questionnaire data could not be compared with the quantitative data acquired from time progression. However, this study found that the psychophysiological method can differentiate the flow level according to time progression. In the future, it may be possible that the flow can be measured in real time if there is a significant enough level to measure the flow by the pupil size.

According to gameplay time progression, in the last part of the game, blink rate was decreased to 0.16 times per second compared to the beginning of the game, during which the blink rate was 0.19 times per second. This is a statistically significant decrease. The result is the same as that when time progressed, subjects tend to not to close eyes much. Also, the blinks duration's percentage decreased in the 10-minutes interval from the initial gameplay and the final one (Kim et al., 2007). The result shows that as the game progressed, the flow level increased, as evinced by the decrease in blinking frequency.

Although the blink rate did not decrease with any statistical significance, the rate of decreasing for each game was -19.8% for the puzzle game, with -10.9% for the coloring and -6.3% for the dot-to-dot. The trend revealed that the puzzle game, having the highest flow level, lessened the blink rate the most, followed by the dot-to-dot game and the coloring game, in that order. The order of decreasing blink rate matches the order from the questionnaire of FSS. Likewise, Nakamori et al. (1997) mentioned that concentration can affect the blink rate. Also, Cho and Shin (2002) report that computer game play resulted in fewer blinks than for typing of documents. These all indicate different levels of concentration level. Concentration is the primary influence of the flow, so a lower blink rate could indicate a higher flow level.

The type of game did not affect the blink rate with statistical significance, so we could not provide clear correlations between blinking and game type. Therefore, it is necessary to study further as to the relationship between the blink rate and flow-level. The difference of blink duration amongst the various game types was not statistically significant. However, depending on the time interval, the blink duration was statistically significant. The puzzle game, having the highest flow level as defined by the questionnaire, resulted in 0.189 seconds of blink duration. It also ranked first in pupil size. The dot-to-dot game resulted in 0.203 seconds of blink duration. It also ranked second in pupil size. Last, the coloring game resulted in 0.183 seconds of blink duration. There were no significant differences in blink duration when the game progressed. The blink duration is a reliable variable related to eye fatigue. Eye fatigue results in the duration of a blink becoming longer than that of a typical blink (Stern et al., 1994; Caffier et al., 2003). The scientifically insignificant results related to blink duration in our study suggests that the subjects did not feel visual fatigue. Therefore, the dilation of pupils and the blink rates would not have been affected by fatigue during the 15-minute experience. If fatigue occurs, the experiment should be calibrated to minimize it and its effects.

5. Conclusion

In this research, concentration level was used as variables to quantify the flow experience effect on pupil size was examined. A questionnaire method was used: an FSS. According to the questionnaire, the puzzle game has the highest flow level. Next game is the coloring, with the dot-to-dot coming in with the lowest flow level. Future research is needed which takes into consideration different possible variables affecting flow such as color stimulation, emotional states, fatigue. The age of participants could have an effect on pupil size within a controlled environment.

Conflict of Interest Statement

None of the authors has any potential conflict of interest.

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