

Ergonomic evaluation of video game playing

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Abstract This study investigated the effect of display type, play-rest schedule and game type on visual fatigue, heart rate and mental workload for both genders during 1 h of Wii game playing. Twenty subjects participated in the experiment. Two display types (a 32-in CRT display and a 32-in plasma display), two different play-rest schedules (10 min play with 5 min rest, repeated four times; 20 min play with 10 min rest, repeated two times) and two Nintendo “Wii Sports” games (boxing and tennis) were used for evaluation. The study results showed that the display and game type had a significant effect on all the measurements. The use of a plasma display to play video games improved the critical flicker fusion (CFF) frequency threshold; however, it also caused a greater subjective eye-fatigue rating, increased heart rate, as well as higher mental workload. Subjects with a 5-min break for every 10 min played had a lower subjective eye-fatigue rating, heart rate and mental workload than with a 10-min break for every 20 min played. The gender effect was not significant on any of the measurements. Implications of the results regarding video-game playing are discussed in terms of display and game type. Playing video games with frequent

short breaks is suggested for reducing visual fatigue, especially for intensive video games.

Keywords Critical flicker fusion frequency · Subjective eye-fatigue rating · Video game · NASA-TLX · TV display

1 Introduction

Computer and video games have become the most popular leisure time activities for people in recent years. The worldwide video game and interactive entertainment industry market will reach \$100 billion in 2019 (DFC Intelligence 2015). The mean age of game players is 35 years old, and they spent about 1 h playing each day (Entertainment Software Association 2015). The main purposes of video game playing are stress relief and enjoyment.

To improve the experience and enjoyment, certain video game playing methods convert a primarily sedentary activity into body movement control, such as the Nintendo Wii (Nintendo[®] Inc., Kyoto, Japan) video game console. Unlike the traditional hand-held video games, Wii adopts a motion-sensitive technology that requires players to act out their characters’ activities, such as swinging the game controller like a tennis racket. The body-movement control game allows users to play the game virtually with real physical exertion. Graves et al. (2007) reported that the energy expenditure in playing “Wii Sports” was at least fifty percent greater than playing traditional sedentary games. However, it is not the same level of energy consumption as playing the sports themselves. Similarly, the research of Scheer et al. (2014) show that playing the Wii Sports boxing game for 8 min increases heart rate, oxygen consumption and ventilation above resting levels, but the

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minimal threshold for moderate-intensity physical activity is not met. However, by extending playing time to 30 min, Wii Sports boxing would provide a moderate to vigorous aerobic response for players (Bosch et al. 2012).

Wii adopts the use of a hand-held wireless controller to operate the game. The controller features a built-in three-axis accelerometer that can detect the hand movements of the user. The PlayStation Move system is similar to the Wii gameplay. For both systems, the user holds a wireless controller and controls the movements through the upper limbs, although the principles of operation of the two systems are not the same. As opposed to the use of hand-held controllers, Xbox Kinect relies on the working principle of motion capture and analysis, allowing users to control the game directly using body movements. Scheer et al. (2014) explored the effects of Nintendo Wii, Xbox Kinect and PlayStation Move on the physiological response of the user. The results showed that regardless of the type of console, the heart rate, oxygen consumption and energy consumption of the subjects during the game were all higher than the resting levels, but no significant difference was observed among the three consoles. Nevertheless, the studies of O'Donovan et al. (2012) and Marks et al. (2015) found that the heart rate, oxygen consumption and energy consumption of the subjects playing Kinect all appeared to be significantly higher than those of the subjects playing Wii, which can be explained by two reasons. First, the game types were different: in the experiment of O'Donovan et al. (2012), the games on the Kinect system required subjects to jump, stretch or bend the torso, while the Wii gaming system only required the subjects to swing their upper limbs; the different motion requirements of different games resulted in differences in physiological response. Secondly, the effect from the game control was different: the study of Marks et al. (2015) asked the subjects to play the same game, but the subjects with Wii handheld controllers could control the game simply by swinging their wrists, while subjects using Kinect had to use larger limb movements for the system to react; therefore, the use of the Kinect gaming system involved a greater physiological cost.

In addition to controlling games, the concept of body-motion control has been applied increasingly in other devices in recent years. For example, De Marsico et al. (2014) developed a system combining hand movements and a 3D mixed-reality visual environment, which can be used in training, system maintenance and medical diagnosis. The user controls the system directly by hand rather than by using a traditional keyboard or mouse, which helps improve operational efficiency and accuracy. However, this device-control method using hand movements is not suitable for the elderly. The study of Fu et al. (2012) found that older people prefer using the touch-panel interface to

joy sticks and traditional remote control. In addition to controlling with hand movements, Westelaken et al. (2011) developed a new aircraft cockpit personal entertainment system. The user may use lower-limb posture and center of gravity of the body to control the game. In comparison with the conventional user interface, the new system allows the user to be more involved in the game. It induces greater lower limb movements, reducing the fatigue of maintaining a sitting position for a long period of time.

Besides physical effects, playing video games may increase mental stress and visual fatigue. Playing complex video games often requires higher-order cognitive skills such as strategic thinking, problem solving and adaptation to rapid change. Yamada (1998) found that the mental workload of playing video games was greater than other visual tasks, such as watching an animation. The amount of mental workload increases with increasing game difficulty (Lin et al. 2008b), and the increase in visual fatigue for video games playing was similar to VDT work (Misawa et al. 1991; Yamada 1998). Miyao et al. (1997) reported that video game playing caused an increase in myopia. Hsu and Wang (2013) indicated that the subjective visual fatigue rating in the first hour of video game playing was approximately constant, but that it increased significantly after 60 min. After 2 h of playing, the subjective visual fatigue rating was four times greater than at the beginning.

For the display effect, a better image quality of display can improve visual task performance and reduce visual fatigue. Menozzi et al. (2001) reported that using a liquid crystal display (LCD) caused fewer errors in visual search tasks than using a cathode ray tube (CRT) display. Wang and Huang (2004) also found that using an LCD display for after-etching inspection (AEI) showed less eye fatigue and better accuracy than using a CRT display. This is due to the better image quality and higher refresh rate of the TFT-LCD display. Furthermore, Takahashi (2006) compared the display effect on visual acuity after 100 min of TV program watching, and found that watching an LCD display had a significantly greater decrease in visual acuity than that of watching a plasma display. The behavior associated with TV program watching is different from TV game playing; users tend to have higher motivation, attention and concentration when playing video games. However, information is lacking about the effects on visual fatigue and mental workload of plasma and CRT displays for video game playing.

Arranging the play and rest schedule is another approach to reduce mental workload and visual fatigue. For reducing mental workload, Boucsein and Thum (1997) recommended that video display terminal (VDT) workers should use a schedule of 7.5 min rest after 50 min of work until noon, and another schedule of a 15-min break after 100 min of work in the afternoon. Balci and Aghazadeh

(2003) compared three work–rest schedules in VDT tasks, i.e., 60 min work and 10 min rest, 30 min work and 5 min rest, and 15 min work and micro-breaks. They reported that the use of 15 min work and micro-breaks, and 30 min work and 5-min break schedules, were found to be more effective in reducing visual fatigue than the others. To date, the effect of play/rest schedules on video game playing has not been addressed in detail and more evaluations are needed.

From Wii console launched in 2006 to recent years, a number of studies have investigated the human responses associated with playing the Wii (Bosch et al. 2012; Graves et al. 2007, 2010; Marks et al. 2015; O'Donovan et al. 2012; Scheer et al. 2014). Thus the study chose Wii to construct the experiments. Moreover, most studies in the past focused on the effects of game console or game type on the physiological reaction, recognition ability and mental workload of the user, while somewhat neglecting the effects of display type and play/rest schedule on visual fatigue. Thus, the objective of this study is to evaluate the effect of display type, play/rest schedule and game type on Wii players' visual fatigue and mental workload. The results of this study can provide useful information for guiding video game playing.

2 Method

2.1 Subjects

Ten male and ten female subjects participated in the experiment. All subjects were free from any known musculoskeletal disorders. Their anthropometric data are summarized in Table 1. All subjects were right-handed and had no previous experience in playing Wii games.

2.2 Experiment design

The independent variables included gender (male and female), display type, play/rest schedule and game type. Subject was a random factor that was nested in the gender factor. Two display types (Fig. 1)—a 32-in CRT display (SC-32WS2) and a 32-in plasma display (PD3231)—were



32-in plasma display

Resolution- 852 x 1024 pixels
Brightness- 650 cd/m²
Contrast- 500: 1
Aspect ratio- 16: 9



32-in CRT display

Synchronization- 15,734 kHz
Dot pitch- 0.82 mm center
Aspect ratio- 16: 9

Fig. 1 The display types used in this study

used for evaluation. Early studies on video games focused on CRT TVs, hence this study used a CRT screen as the control group. However, a number of more recent studies discussing game-playing behavior also used plasma displays as the display media (Griffiths et al. 2016; Hsu and Wang 2013; Marks et al. 2015; Williams 2014). Hence, this study used plasma displays as the experimental group, so as to compare the effect of different displays on body fatigue and mental workload.

Moreover, two different play/rest schedules (i.e., 10 min play with 5 min rest, repeated four times (P10R5); 20 min play with 10 min rest, repeated two times (P20R10)) and two Nintendo “Wii Sports” games (boxing and tennis) were specified in the study. Each subject played for a total of 40 min and rested for 20 min in 1 h of game playing. A nested factorial design was employed, and a total of 8 experimental combinations were conducted by each subject.

2.3 Dependent variables

The dependent variables included the following.

2.3.1 Objective visual fatigue measure

The critical flicker fusion (CFF) frequency was measured by a CFF tester (TAKEI TK502) to assess the subject's visual fatigue and visual sensory sensitivity. CFF is a psychophysical test of the visual temporal resolution. It measures the minimal number of flashes per second at which an intermittent light stimulus no longer generates a continuous sensation. The flicker frequency was measured in two different ways: (1) the frequency was increased from 5 to 60 Hz until the subject perceived fusion; (2) the frequency was decreased from 60 to 5 Hz until flicker was

Table 1 Anthropometric data of the participants

	All (n = 20)	Female (n = 10)	Male (n = 10)
Age (years)	27.0 (4.4)	27.3 (4.2)	26.7 (4.7)
Body height (cm)	167.6 (7.0)	162.6 (4.0)	172.7 (5.6)
Body weight (kg)	62.1 (12.5)	56.5 (9.3)	67.8 (13.2)

(), standard deviation

detected. The average frequency of the two tests was taken as the CFF measure in a given condition. The CFF was tested at the beginning and the end of each experiment session. The change in frequency before and after the experiment was calculated. An increase in CFF threshold indicates an increase in visual sensory sensitivity. On the contrary, a decrease in CFF threshold indicates an increase of visual fatigue (Li et al. 2004).

2.3.2 Subjective visual fatigue assessment

The subjective visual fatigue level was assessed by using a 1–20 rating scale, with 1 denoting ‘nothing at all’ and 20 denoting ‘extreme fatigue’ (Wang and Huang 2004). The eye fatigue rating was taken at the end of each experiment session.

2.3.3 Heart rate

The heart rate was measured by using a heart rate monitor (Polar® plus). The transmitter was positioned on the left side of the subject’s chest. The resting heart rate was measured as the base-line reference before each test.

2.3.4 Mental workload measures

The subjective mental workload was assessed by using the NASA Task Load Index (NASA-TLX) (Hart and Staveland 1988). NASA-TLX is a multidimensional mental workload rating that contains six factors: mental demand, physical demand, temporal demand, performance, effort and frustration level. Workload assessment using the NASA-TLX is a two-step procedure. First, the subject evaluates the weighting of each of the six factors through pair-wise comparisons. Next, the subject gives numerical ratings to each of the six factors. The rating scale ranged from ‘low’ to ‘high’ in linguistic terms for all factors except for the ‘performance’ factor, which is rated from ‘poor’ to ‘good’. The overall workload score is calculated by the weighted average of the ratings ranging from 0 to 100.

2.4 Experimental procedure

The experimental procedure involved preparation, playing and ending phases, as illustrated in Fig. 2. In the preparation phase, the subjects’ height and body weight were measured. The objective visual fatigue measure (CFF) was taken as the baseline data for comparison. In the video game playing phase, each subject completed a practice session for both tennis and boxing games. The subject was allowed to freely adjust the viewing distance while playing. The heart rate was measured during video game playing. In the ending phase, the subjective visual fatigue rating, CFF,

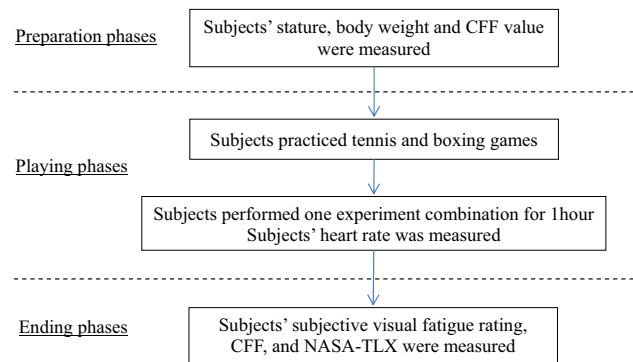


Fig. 2 The flowchart of experimental procedure

and NASA-TLX measures were taken. The CFF difference before and after the experiment was calculated. The situations of game playing and CFF measuring are illustrated in Fig. 3.

3 Results and discussion

3.1 Display type effect

The analysis of variance results in Table 2 reveals that the effect of display type was significant on CFF change ($p < 0.001$), eye-fatigue rating ($p < 0.01$), heart rate ($p < 0.001$), as well as NASA-TLX scores ($p < 0.05$). Table 3 presents the mean values of the four independent variables.

Table 3 shows that the CFF increase was higher for game playing with plasma displays than with CRT displays. An increase in CFF change indicates an increase in visual sensitivity. The reason was probably because the better definition of the plasma display increased the subjects’ attention to play and resulted in an increase in visual sensitivity. Some previous studies also showed some positive results that video game playing would shorten reaction time (Yuji 1996), enhance visual attention (Green and Bavelier 2003), enhance visual short-term memory (Green and Bavelier 2006) and increase visual acuity threshold (Green and Bavelier 2007). However, some negative effects were also reported. Playing video games on plasma displays produced an increase of 17 % in eye fatigue rating, 5 % in mental workload and 3 % in heart rate over playing video games with CRT displays (Table 3). The better image quality of the plasma display increased the subject’s motivation to immerse him/herself in the game, increased the effort in playing, and resulted in an increase of subjective eye fatigue, heart rate, and mental workload.

Moreover, the interaction of display and game type significantly affected the subjective eye-fatigue rating ($p < 0.05$) as shown in Table 2 and Fig. 4. When playing

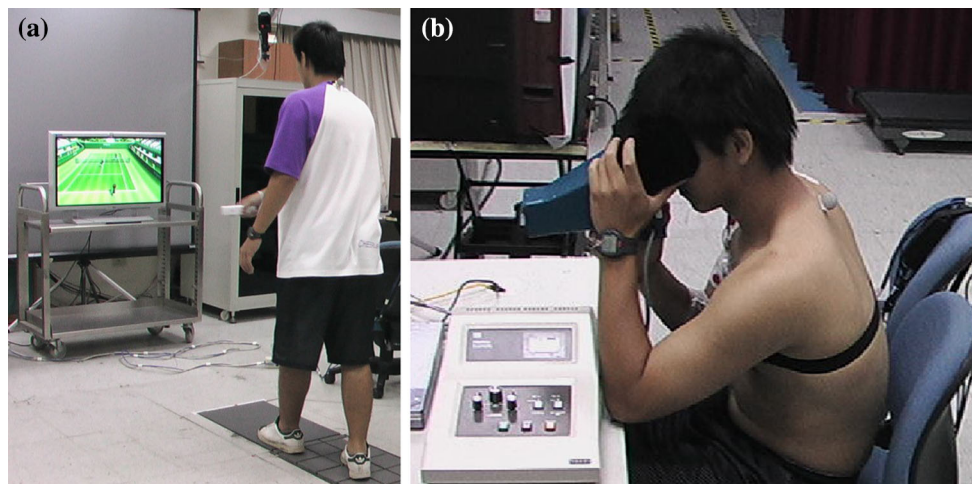


Fig. 3 Illustration of the experimental setting. **a** A subject was playing tennis game. **b** The critical flicker fusion (CFF) frequency was measuring and the heart rate monitor was positioned on the subject's chest

Table 2 ANOVA results

Source	df	CFF change	Eye fatigue rating	Heart rate	NASA-TLX
Display (D)	1	***	**	***	*
Play–rest schedule(P)	1	***	***	***	
Game (G)	1	***	***	***	***
Gender (Ge)	1				
D × P	1	*		*	
D × G	1		*	*	
D × Ge	1				
P × G	1		*	**	
P × Ge	1				
G × Ge	1		*	*	
D × S[Ge]	18				
P × S[Ge]	18				*
G × S[Ge]	18		**	***	***
Subject (Gender)(S[Ge])	18		***	***	*

* Significant at $p < 0.05$, ** significant at $p < 0.01$; *** significant at $p < 0.001$

an intensive sport game such as boxing on a plasma display, the eye-fatigue feeling was about 20 % higher than playing on a CRT display. However, the eye-fatigue feeling was similar for both displays while playing the less intensive tennis game. It seems that the influence of display type on visual fatigue is less for the less intensive video game.

Furthermore, the CFF change was significantly affected by the interaction of display type and play/rest schedule ($p < 0.05$). Figure 5 shows the interaction effect. When playing with the P10R5 schedule, the CFF change with a plasma display was about 20 % higher than with a CRT display. Moreover, when playing with P20R10 schedule, the CFF change with a plasma display was about 45 % higher than with a CRT display. Indeed, the difference in

CFF change between different experiment levels was rather small, even though the main effect was significant. This result is frequently encountered in CFF measures, and a significant difference should not be ignored however small it may be. For example, the study results of Lin et al. (2008a) showed that the CFF difference between different visual tasks can be as little as 0.03 Hz but still be significant.

3.2 Play/rest schedule effect

As shown in Table 2, the effect of the play/rest schedule was significant on CFF change, eye-fatigue rating and heart rate ($p < 0.001$). However, the play/rest schedule showed no significant influence on mental workload. The results in

Table 3 The response measurements under different level of the independent variable

	CFF change (Hz)	Eye fatigue rating (scores)	Heart rate (bpm)	NASA-TLX (scores)
Display type				
CRT display	1.02 (0.61)	3.86 (1.94)	89.53 (10.47)	46.83 (13.82)
Plasma display	1.37 (0.81)	4.50 (2.09)	92.40 (11.02)	48.77 (13.89)
Play–rest schedule				
P10R5	1.01 (0.62)	3.85 (1.80)	89.24 (9.81)	48.07 (13.75)
P20R10	1.39 (0.79)	4.51 (2.21)	92.68 (11.53)	47.53 (14.02)
Game type				
Tennis	0.78 (0.48)	3.10 (1.54)	83.92 (6.57)	42.58 (12.86)
Boxing	1.62 (0.70)	5.26 (1.90)	98.00 (9.57)	53.02 (12.85)
Gender				
Male	1.23 (0.75)	4.11 (2.13)	89.80 (11.33)	44.05 (14.54)
Female	1.17 (0.72)	4.25 (1.95)	92.13 (10.20)	51.55 (12.07)

(), standard deviation

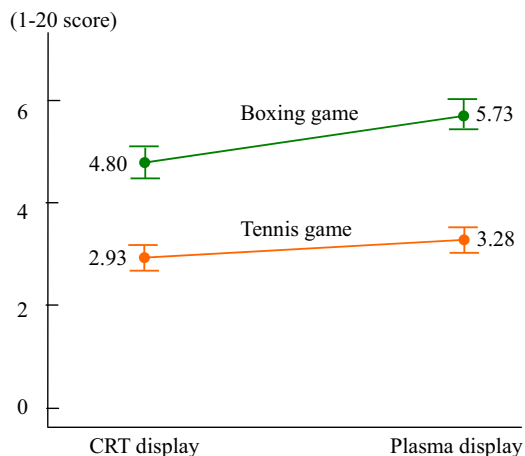


Fig. 4 The interaction effect of display × game on eye fatigue rating. Error bars represent the standard error of the mean

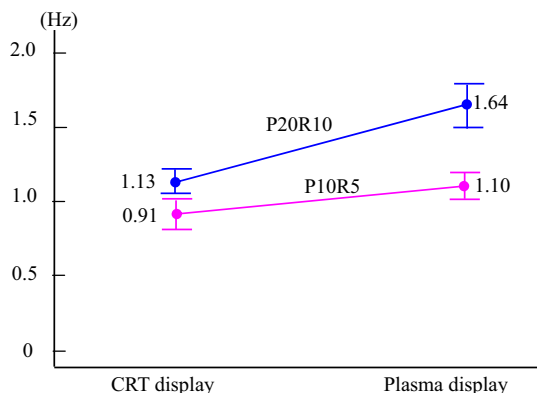


Fig. 5 The interaction effect of display × play–rest schedule on CFF change. Error bars represent the standard error of the mean

Table 3 show that playing with the P10R5 schedule produced about 70 % of the CFF change and 85 % of the eye-fatigue rating as compared to playing with the P20R10 schedule. Balci and Aghazadeh (2003) and Galinsky et al. (2000) also reported that a frequent rest schedule was more effective in reducing eyestrain and body-fatigue feeling.

The interaction effect of play/rest schedule and game type was significant on eye-fatigue rating ($p < 0.05$) and heart rate ($p < 0.01$), as shown in Table 2. Figure 6 shows the interaction effect of play/rest schedule and game type on eye-fatigue rating. The eye-fatigue rating was similar for both play/rest schedules while playing the less intensive tennis game. However, the eye-fatigue rating for playing the more intensive boxing game with the P20R10 schedule was found to be 20 % higher than playing with the P10R5 schedule. Thus, the visual-fatigue feeling showed a higher increase when playing the intensive game with less frequent breaks. Figure 7 shows the interaction effect of play/

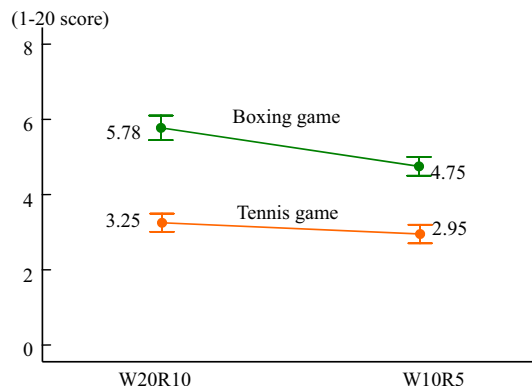


Fig. 6 The interaction effect of play-rest schedule × game on eye fatigue rating. Error bars represent the standard error of the mean

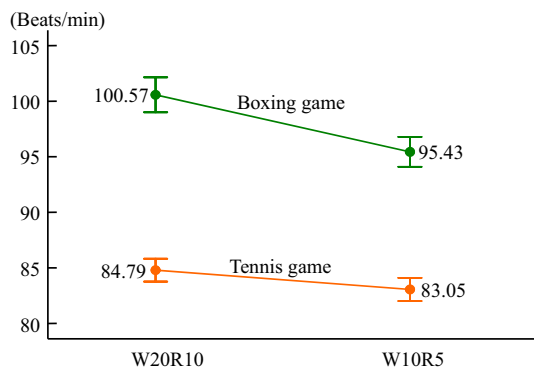


Fig. 7 The interaction effect of play–rest schedule \times game on heart rate. Error bars represent the standard error of the mean

rest schedule and game type on heart rate. The subjects' average heart rate was about 7 % higher when playing the boxing game with the P20R10 schedule than when playing the same game with the P10R5 schedule. On the other hand, the average heart rate of the two schedules was similar while playing the less intensive tennis game. Frequent short breaks during video game playing would lower the accumulation of eye fatigue and physical workload for the intensive boxing game. Thus, the effect of reducing visual fatigue using the P10R5 schedule is becoming more obvious than using the P20R10 schedule when playing an intensive sport game such as boxing.

3.3 Game type effect

The effect of game type was significant on all the response measures ($p < 0.001$). The results in Table 3 reveal that the change in CFF for playing the intensive boxing game was almost double that of playing the less intensive tennis game. The intensive and exciting boxing game caused the subjects to allocate more mental resources to visual attention, and thus increased their visual sensitivity.

On the other hand, playing the boxing game produced about 75 % more eye-fatigue feeling than playing the tennis game. It seems that exposure to the more dynamically changing images and moving objects while playing the intensive boxing game induced a higher level of visual fatigue. Additionally, playing the boxing game produced about a 20 % increase in heart rate and mental workload than playing the tennis game (Table 3). The prolonged attention and fast reaction required in playing the intensive and exciting boxing game resulted in a higher mental and physical workload for the player.

3.4 Gender effect

Table 2 reveals that the gender effect was not significant for any of the measures. However, the interaction effect of

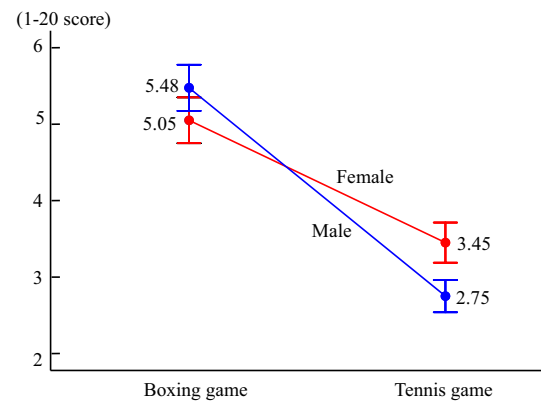


Fig. 8 The interaction effect of gender \times game on eye fatigue rating. Error bars represent the standard error of the mean

gender and game was significant on subjective eye-fatigue rating ($p < 0.05$) as shown in Table 2 and Fig. 8. The eye-fatigue rating in playing the boxing game was higher for both genders than in playing the tennis game. Furthermore, it is interesting to note that the eye-fatigue rating in playing the boxing game was double that of playing the tennis game for males. For females, the eye-fatigue rating when playing the boxing game increased by about 50 % compared to the eye-fatigue rating when playing the tennis game. For males, there is a higher eye-fatigue rating for playing the boxing game, and a lower eye-fatigue rating for playing the tennis game than those of females. Lucas and Sherry (2004) indicated that males prefer to play the more intensive competition games, and thus their motivation and involvement tend to be higher when playing the boxing game. On the other hand, females prefer the challenging but less exhausting games, and thus have a higher interest and involvement in playing the tennis game.

3.5 Research limitations

This study has several constraints. First, the number of subjects was small and the age group was narrow, making the results more applicable to 22- to 30-year-old adults. Graves et al. (2010) indicated that adolescents and young adults having significantly greater energy expenditure compared with older adults while playing Wii Fit game. The exercise intensity of Wii Sport game is greater than Wii Fit game, thus the physiological responses, visual fatigue and mental workload might be different from different age groups. The second is the impact of game experience of the subject—the results of this study are more suitable for people with no previous experience with Wii. O'Donovan et al. (2012) reported that players with greater gaming experience could achieve a lower heart rate than less experienced players. The both responses of visual fatigue and mental workload might be different from

different gaming experience groups. Thirdly, the subjects were aware that their gaming process would be observed and recorded, which might have influenced their actions, resulting in variations from their actual game-playing behavior (Marks et al. 2015).

4 Conclusion

The objective of this study was to evaluate the effect of display type, play/rest schedule, game type and gender on visual fatigue, heart rate and mental workload for Wii players. The study results showed that a better display quality (plasma display) and a more intensive game (boxing) increased players' motivation and visual sensitivity (CFF threshold increased); however, it also caused an increase in eye fatigue, and physical as well as mental workload. Thus, it is necessary to adopt a frequent-break schedule while playing more intensive games such as boxing.

As for the contributions of this paper, first of all, the results of this study can be applied to systems that also use body movements to control the game, such as Xbox Kinect and PlayStation Move. The results can be viewed as usage recommendations for the increasingly popular motion-sensing games, in order to enhance the positive effects and reduce the negative impacts of game playing. Secondly, the study provides computer-operating personnel with a work/rest reference. While working, short rests will help reduce visual fatigue and relieve mental workload, which improves the overall working efficiency. This study suggests that in the future, more combinations of age groups, game types, and play/rest schedules should be explored in order to further discover their effects on the physiological and cognitive reactions of game players. In addition, the game elements capable of eliciting the highest motivation in game players should be found, to further strengthen those elements and enhance the enjoyment of games.

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