Psychophysiology of flow experience:

An explorative study

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Abstract

This study explored the possibilities the psychophysiological methodology offer to flow research. Facial electromyography has often been used to index valence, and electrodermal activity to index arousal, the two basic dimensions of emotion. It was hypothesized that these measures can also be used to examine enjoyment, a basic component of flow experiment. A digital game was used to induce flow, and physiological activity of 32 subjects was measured continuously. Flow State Scale was used to assess flow.

Activity of corrugator supercilii muscle, an index of negative valence, was negatively correlated with flow reports, as hypothesized. Contrary to hypothesis, skin conductance level, an index of arousal, was unrelated to self-reported flow. The results for association between flow and zygomaticus major and orbicularis oculi muscle activities, indices of positive valence, were inconclusive, possibly due to experimental design where only tonic measures were available.

Psychophysiological methods are recommended for future studies of flow. Specifically, the time series approach may be particularly viable in examining the temporal aspects of flow, an area currently unexplored. Furthermore, it is suggested that digital game research would benefit from psychophysiological study of game-related flow.

Keywords: Flow, pleasure, psychophysiology, facial expression, corrugator supercilii, zygomaticus major, orbicularis oculi, skin conductance, digital games

Tiivistelmä

Tutkimuksessa selvitettiin psykofysiologisien menetelmien tarjoamia mahdollisuuksia flow'n tutkimukselle. Kahden emootioiden perusulottuvuuden, valenssin ja kiihtymyksen, tutkimiseen on usein käytetty kasvolihastoiminnan ja ihon sähkönjohtavuuden mittaamista. Hypoteesina oli, että näitä menetelmiä voi myös käyttää mielihyvän, flow'n peruskomponentin, tutkimiseen. Flow-kokemuksen synnyttämiseen käytettiin digitaalista peliä, ja 32 koehenkilöltä mitattiin tooninen fysiologinen aktiviteetti. Flow State Scale –kyselyä käytettiin flow'n arvioimiseen.

Hypoteesin mukaisesti negatiiviseen valenssiin yhdistetty corrugator supercilii –lihaksen aktiviteetti korreloi negatiivisesti flow-kyselyn tulosten kanssa. Hypoteesin vastaisesti kiihtyneisyyttä ilmaiseva ihon sähkönjohtavuuden taso ei ollut yhteydessä raportoituun flow-tasoon. Tulokset positiiviseen valenssiin yhdistettyjen zygomaticus major ja orbicularis oculi –kasvolihaksien aktiviteettien suhteesta flow-tasoon eivät olleet ratkaisevia, johtuen mahdollisesti toonisiin mittauksiin perustuvasta koeasetelmasta.

Psykofysiologisia metodeja suositellaan käytettäväksi tulevissa flow-tutkimuksissa. Erityisesti aikasarja-lähestymistapa saattaa olla erityisen käyttökelpoinen tarkasteltaessa flow'n ajallisia ominaisuuksia, joista tällä hetkellä ei ole lainkaan tutkimusaineistoa. Lisäksi esitetään, että digitaalisten pelien tutkimus hyötyisi pelien aikana tapahtuvan flow'n psykofysiologisesta tutkimuksesta.

Avainsanat: Flow, mielihyvä, psykofysiologia, ilmeet, corrugator supercilii, zygomaticus major, orbicularis oculi, ihon sähkönjohtavuus, digitaaliset pelit

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Contents

List of abbreviations

CS	Corrugator supercilii, a muscle located above brow, used in frowning
EDA	Electrodermal activity, i.e. changes in skin conductance
EMG	Electromyography, i.e. measuring the contraction of muscles
FPS	First-person shooter, a shooting game viewed from the game character’s eyes
FSS	Flow State Scale (Jackson & Marsh, 1996)
OO	Orbicularis oculi, a muscle located below eye, used in widening the eye
SCL	Skin conductance level
WWW	World wide web
ZM	Zygomaticus major, a muscle located on cheek, used in smiling

1 Introduction

The concept of flow was first introduced by Mihaly Csikszentmihalyi in his book Beyond Boredom and Anxiety (1975), while attempting to find out what drove people in free-time activities that did not seem to follow the utility-centered motivational theories of the time. From several interviews he derived what appeared to be a form of intense engagement and enjoyment, which he named *flow*. The phenomenon is easily recognized by most people, experienced equally during sports, work, artistic performance and many other activities. Yet, after three decades of research, the understanding of flow is still fragmented (see, for example, Novak, Hoffman & Yung, 1998).

In addition to being an immensely popular entertainment, digital (for example computer and console) games are more and more used for therapeutic, educational, and work-related purposes (e.g., Amory, Naicker, Vincent & Adams, 1999; Griffiths, 2003). Playing digital games can provide experiences which could be described as flow experience. It is enjoyable and highly engaging activity, it involves intrinsic motivation, and it is commonly known to cause also other experiences similar to flow, such as losing the track of time and a state where the outside world seems to disappear or lose importance. Some recent academic studies have connected flow and gaming (e.g. Asgari, 2005; Choi & Kim, 2004; Hsu & Lu, 2004), and indeed, flow could be considered a major reason for people to continue playing digital games.

The association between flow and games is not easy to study. The field of digital gaming research is new and there is no ready method assessing flow in this specific context. Studies that have used flow in human-computer interaction context have regularly created new models to assess flow in their special field (e.g., Finneran & Zhang, 2003; Hoffman & Novak, 1996; Pace, 2004), but none of these has gained a general acceptance.

The purpose of this study is to explore how flow research could benefit from using psychophysiological methods. The secondary aim is to introduce the concept of flow to digital games research and digital games to flow research.

1.1 Previous studies on flow

Originally (Csikszentmihalyi, 1975) flow was associated with the enjoyment derived from various sports and other leisure activities, leading to motivation to re-enter in those activities. According to the theory the activity inducing flow becomes autotelic, worth doing in itself, instead of being a way to achieve something else. This effect has also later been found in work settings, connecting it to work satisfaction (Csikszentmihalyi & LeFevre, 1989). Later flow has been connected to increased learning (Craig, Graesser, Sullins & Gholson, 2004), creativity (Csikszentmihalyi, 1996), and life satisfaction (Csikszentmihalyi, 1990).

In human-computer interaction field flow has been studied in order to improve the interaction situation or the quality of work (e.g., Hoffman & Novak, 1996; Trevino & Webster, 1992). In these studies flow has been associated with increased positive affect (Trevino & Webster, 1992), exploratory behavior (Ghani & Deshpande, 1994), and computer use (Ghani & Deshpande 1994; Trevino & Webster 1992). Around year 2000 many scholars published studies concerning flow in the WWW environment (e.g., Chen, Wigand & Nilan, 1999; Novak, Hoffman & Yung, 2000; Skadberg & Kimmel, 2004, Woszczynski, Roth & Segars, 2002). The conclusion was that taking flow into account when designing Web pages should help making them more appealing.

Studies focused on designing digital games have recently noticed the same potential in flow. Several studies have found that one reason for playing digital games is the flow experience (e.g., Choi & Kim, 2004; Gilleade, Dix & Allanson, 2004; Schneider, Lang, Shin & Bradley, 2004). The conclusion is the same: if one knew more of how flow works, using that knowledge in the game designs could help creating more appealing games.

1.1.1 Flow models

Csikszentmihalyi (1975) attributed the flow to the situation where the person is performing on the edge of his or her abilities. According to this model, flow can occur when the challenge provided by the activity is high enough but the skills of the person can still control the situation (i.e. challenge and skills are balanced and on high enough level; see figure 1).

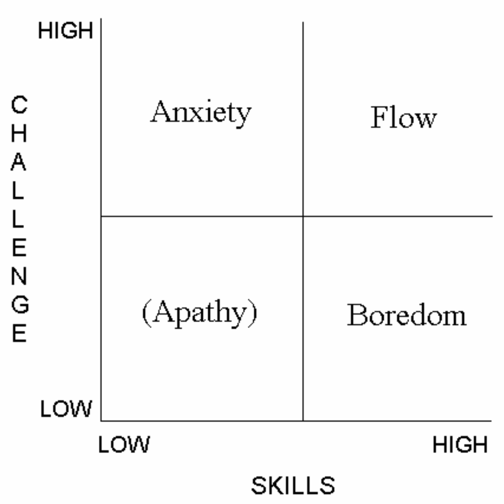

Figure 1. The four-channel model of flow. According to this model, flow can occur when both challenges and skills are high. High challenges but low skills result in anxiety, the reverse situation results in boredom. Apathy is later, and rather controversial, addition. Adapted from Ellis, Voelkl & Morris, 1994.

The four-channel model was the first and has since been the most used flow model, but concerns about how the concept should be operationalized have emerged (see, i.e., Ellis, Voelkl & Morris, 1994). The model does not specify how the challenge and skills should be assessed, how “high” is defined, or what “the balance” means. It has also been reported that people actually enjoy more a situation where skills are greater than challenges than a situation where both are high (Carli, Delle Fave & Massimini, 1988; Clarke & Haworth, 1994; Ellis et al., 1994).

The four-channel model has not been regularly used in the human-computer interaction studies (although see Pearce, Ainley & Howard, 2005, for an exception). Chen and coworkers argued: “Past operationalizations of flow have employed measures that ask subjects about ‘challenges’ they perceived and their ‘skills’ in meeting and overcoming the challenges. We think that these operationalizations are unlikely to be understood by subjects in all but the most mundane activities (e.g. playing a physical sport), thereby generating unreliable definitions.” (Chen et al., 1999, p.592) They state that in case of a complex activity such as “using the Web”, asking directly about the challenges or skills is likely to only get the respondents confused.

Most flow researchers in human-computer interactions field have used different operationalizations of flow in their studies. Unfortunately, no model has reached a wider acceptance. In their review section Novak, Hoffman and Yung (1998) listed 16 flow studies from 1977 to 1996 and tabulated concepts used in these studies (such as control, positive affect, concentration and other concepts commonly used in flow research). Apart from the four-channel model used in three of them, no two studies employed the same set of concepts in creating their construct of flow. After 1998, many human-computer interaction-related flow studies have introduced a model of their own (e.g., Chen et al., 1999; Finneran & Zhang, 2003; Skadberg & Kimmel, 2004). In these studies flow has been operationalized by an ad hoc questionnaire with no further development or validation studies, with the exception of work by Novak, Hoffman, and colleagues (Hoffman & Novak, 1996; Novak et al., 2000; Novak, Hoffman & Duhachek, 2003).

Even outside the human-computer interaction field there appears to be only one instrument for flow research which has been validated and evaluated for several times: Jackson and Marsh's (1996) Flow State Scale (FSS) (Marsh & Jackson, 1999; Stavrou & Zervas, 2004; Tenenbaum, Fogarty & Jackson, 1999; see also Vlachopoulos, Karageorghis, & Terry, 2000, for a critique). It is based on the nine flow characteristics introduced by Csikszentmihalyi (1990, see appendix A), presenting a flow continuum instead of a clear-cut state. FSS was developed for use in sports research—there is no data of its reliability or validity in digital gaming or in other human-computer interaction contexts.

1.2 The current approach

Flow has been studied primarily with questionnaires, and, more rarely, interviews. However, as a key characteristic of flow is the intense concentration on activity, the introspection essential for these methods is necessarily suppressed when flow is occurring (Csikszentmihalyi, 1990). No research on how this affects these methods was found.

Psychophysiological measures can be taken covertly during the flow experience without any participation from the subject. They also have additional benefits: They are not dependent on subject's memory or interpretation of questions, and the subject need not be conscious of the processes assessed by psychophysiological recordings. Physiological processes can also be monitored and recorded continuously. This allows a completely novel research of how flow plays out in time.

But what are the physiological concomitants of flow? Looking at the various existing definitions (see e.g., Novak et al., 1998) can leave one confused. Ultimately the vague descriptions of flow provided in early studies (Csikszentmihalyi, 1975; Csikszentmihalyi, 1990; Csikszentmihalyi & Csikszentmihalyi, 1988) are still the only thing that researchers widely agree upon. From these and later (e.g., Chen et al., 1999; Pace, 2004) descriptions two components can be derived that are always present: *enjoyment* and *focused attention*. These two are also, in form or another, typically a part of the various flow constructs used (see Novak et al., 1998; see also Ellis et al., 1994). Indeed, enjoyment and focused attention could be seen as basic components that constitute the flow experience, without taking a stand on its conditions or consequences.

It should be noted that typical psychophysiological research that relates to these basic flow components measure phasic changes in physiological activity—that is, changes relating to a specific event or stimulus. As flow is not a phenomenon that can be associated with a particular event but rather with a more ambiguous, longer period of time, only those methods that can also be used to examine changes in tonic (i.e. long-term) activity are applicable.

1.2.1 Psychophysiology and enjoyment

Damasio (2001) emphasizes the following distinction: Emotions are directly observable and open for investigation by the automatic physiological reactions they induce in the body; feelings are the mental representations of emotions, and private to the person experiencing them. Enjoyment falls to the latter category. According to Damasio, feelings are direct consequences of emotions, although the mechanism is not fully understood. Still, as feeling of enjoyment derived from flow is supposed to be significantly strong (Csikszentmihalyi, 1990) its emotional counterpart should be measurable by physiological changes.

In psychophysiological emotion research it is suggested that all emotions can be located in two-dimensional space of *valence* and *arousal* (Lang, 1995). The arousal dimension of emotion is the extent of bodily activation, from low to high. The tone of this activation, for example the difference between rage and exhilaration in case of extreme arousal, is depicted on the valence dimension. According to Lang (1995), enjoyment—or the emotion related to that feeling—is located at high valence and mid-to-high arousal.

Although there is variability in the use of these dimensions, the simple combination of valence and arousal is most often used in psychophysiological research. Arousal is connected to electrodermal activity (EDA, or skin conductance), and valence to facial electromyography (EMG) (Lang, Greenwald, Bradley & Hamm, 1993).

Measurement of skin conductance, usually on palms of hands, is one of the most often used physiological measurements and a well-established index for emotional arousal (Dawson, Schell & Filion, 2000; Lang et al., 1993). Unlike many other physiological responses, the neural control of eccrine sweat glands – the basis of electrodermal activity – is predominantly under sympathetic nervous system (SNS) which regulates the mobilization of the human body for action (Boucsein, 1992; Dawson et al., 2000). Skin conductance level (SCL) is the measure of tonic EDA.

The use of facial electromyography, or measuring the contraction of facial muscles, is based on the facial expressions associated with emotions, both overt and covert (Lang et al., 1993). Facial expressions can also be rated by observation, but in addition to benefits of reliability and automatization, the EMG has been shown being able to capture activity at a lower level than could be detected visually (Tassinary & Cacioppo, 2000). The measurement of the activity of corrugator supercilii (CS, brow muscle, used in frowning), zygomaticus major (ZM, cheek muscle, used in smiling), and orbicularis oculi inferior (OO, muscle below the lower lid, used in widening the eye) muscle areas can be used to discriminate emotional expressions, especially when concentrating on emotional valence instead of discrete emotions (Bradley, 2000). The activity on CS and ZM muscle areas is shown to be connected to negative and positive emotions, respectively (Lang et al., 1993). OO, in turn, has been associated with enjoyment smile and genuine pleasure (Ekman, Davidson & Friesen, 1990).

1.2.2 Psychophysiology and digital games

Although the majority of psychophysiological research is composed of studies where stimuli are passively viewed or listened there is evidence that similar psychophysiological principles hold with interactive digital games. Ravaja and coworkers (Ravaja et al., 2004) found an association with presence ratings and phasic physiological measures indexing valence (EMG on ZM and CS) and arousal (SCL), taken during a digital game. They (Ravaja et al., in press) also found differences in arousal (tonic cardiac measures) depending on the opponent: a single player game elicited lower arousal levels than multiplayer games, and a multiplayer game played against a stranger elicited lower arousal levels than one played against a friend.

In a study by van Reekum and coworkers (van Reekum et al., 2004) measures of phasic EDA and cardiac activity among other physiological responses were used to assess participants' emotional reactions to different events during digital game. Physiological measures were found to be associated with arousal and goal conduciveness.

1.3 Current study

An experimental study was conducted to examine the associations between physiological measures and self-rated flow scores assessed by the FSS (Jackson & Marsh, 1996). The participants played a popular digital game, during which the physiological activity was recorded continuously. Three facial EMG measures were used to index emotional valence (ZM and OO positive, CS negative valence) and skin conductance measure (SCL) was used to index emotional arousal.

By definition (e.g., Csikszentmihalyi, 1990; Ellis et al., 1994; Trevino & Webster, 1992) the flow experience is a state of highly positive emotional valence and heightened arousal. Therefore it was hypothesized that participants scoring high on FSS would also have high positive valence (indicated by high ZM and OO EMG activity and low CS EMG activity), and high arousal (indicated by high SCL), when compared to participants with lower FSS scores.

2 Methods

2.1 Participants

Participants were 32 male volunteers, recruited with an invitation placed on university mailing lists and on discussion forum for the subscribers of the largest Finnish gaming magazine (Pelit; see http://www.pelit.fi). The age ranged from 17 to 34 (M = 24.25) years. Participants were in good health, they all had at least some gaming experience, and they reported liking FPS (first person shooter) games. The last requirement was included to ensure that it was possible for the participants to experience flow, as relevant experiences are reported most often with experienced players (Choi & Kim, 2004), and flow is supposed to be a rare event (Csikszentmihalyi, 1990). The participants received no monetary compensation, but two game-related 30 euro prizes were drawn between them.

2.2 Gaming equipment

The game used in this study was Halo: Combat Evolved (Bungie Studios, 2003). The game was chosen because among the generally acclaiming reviews there were often references to the intense experience the game provided (e.g., Kasavin, 2003; Honkala, 2003). Furthermore, because the initial publishing was not on PC but on Xbox, supposedly fewer PC players had tried it previously. The conversion has been reviewed as being of good quality (Kasavin, 2003).

The game is a science fiction first person shooting game with a heavy emphasis on story, situated on an alien world in the far future. In Halo the player's character is depicted as distinctly superior soldier who is always hailed with joy by outgunned humans, and recognized and even feared by the otherwise overpowering aliens. This arguably creates an atmosphere where the player feels he is the main character in an epic science fiction war story. The chapters the participants played were Pillar of Autumn, Halo, and Assault on the Control Room, for introductory, game period I, and game period II, respectively. In addition to first-person action, these chapters also include story-related in-game movies, radio messages, and discussions between the game characters. The chapters contain also some third person viewed periods where the player gets to pilot jeeps, tanks, or different kinds of alien hovercrafts.

The hardware running the game was an Intel P3-866, 256Mt RAM, ATI RADEON 9200 (128MB), SB Audigy with BeyerDynamic DT311 earphones, and Sony Trinitron 17" monitor. The game was run in resolution of 800x640 with low graphical settings to prevent the limitations of hardware resulting in low frame rates. Standard FPS mouse and keyboard configuration was used, as most of the PC gamers are accustomed to these controls. Sound volume, screen location, mouse handedness, and key definitions were also set as comfortably for the participant as possible, and if desired, participants could change these settings. Participants also set the difficulty level (easy, normal, hard, or very hard) up to their preferences in the game periods, although they were given guidelines of the general difficulty of the game. The aim was to provide the participants a playing environment as close to their normal environments as possible. Only one participant chose a difficulty level lower than normal and one a difficulty level higher than normal, one participant chose to change handedness and one the key definitions.

2.3 Procedure

The study took place in an electrically shielded and sound-attenuated, lightly-lit room, in which a computer screen, controllers, and an comfortable armchair were set up. All measuring equipment and the hardware running the game were located in the adjacent room.

The participant was briefed about the general purpose of the study after which he filled in an informed consent form and the preliminary questionnaire (background survey, valence and arousal ratings). Next the participant was taken to the laboratory and electrodes were attached while he read written instructions and familiarized themselves with the game manual. During the study researcher tried to maintain friendly and relaxed atmosphere in order to reduce arousal incited by new situation and environment.

The main body of the study consisted of four periods while physiological activity was recorded continuously. *Baseline period* was five-minute long, during which the participant was told to relax and focus on the fixation cross in the middle of the empty screen. The length of the *introductory* period varied from 11 to 25 minutes. The participant watched the four-minute starting movie and played until he was familiar with the gameplay, roughly to the point after the first combat situation. Only during introductory period the researcher was present in laboratory, guiding the participant about the controls and game mechanics. In *game period I* the participant was instructed to play as he liked, starting from a predefined point, until the researcher came back to give more instructions. After 40 minutes the researcher came in to pause the game, and asked if the participant wanted to have a break (no participant did). *Game period II* was another 40-minute game period similar to the first, only the starting point differed. The two game periods were separated to give the participants an opportunity to have a break. It also served to provide them a more diverse gaming experience, as the two chosen chapters from the game contained different types of in-game situations. During the two game periods the researcher monitored the game situation via a secondary video output to check that participants followed the instructions.

After the electrodes were detached the participants were taken to the adjacent room where they filled in the questionnaires (valence and arousal ratings, FSS). After the study, if desired, the participants were given a more detailed explanation of the study and physiological measures, but asked to keep the information from other potential participants.

2.4 Physiological measurements

2.4.1 Facial EMG activity

EMG responses were monitored from the muscle sites of corrugator supercilii (CS), orbicularis oculi (OO), and zygomaticus major (ZM). The participant's skin was cleaned with low-alcohol detergent and the muscle sites were rubbed slightly to ensure that the electrode impedance was lower than 10 kΩ. An electrode electrolyte (Med Assoc., St. Albans, VT) and surface Ag/AgCl miniature electrodes (4 mm in diameter; Med Assoc.) were inserted on the left side of the face following the guidelines of Fridlund and Cacioppo (1986). The activity (μV) was recorded at the bandpass of 20 - 500 Hz with Mespec 4000 equipment (Mega Electronics Ltd., Kuopio, Finland). The EMG signals were sampled at a rate of 2000 Hz, digitized with a 12-bit 8-channel A/D converter, and integrated with a time constant of 1000 ms.

2.4.2 Electrodermal activity

Electrodermal activity was recorded with a self-balancing SC4 amplifier (Contact Precision Instruments, London, UK). Beckman Ag/AgCl skin electrodes were attached onto the medial side of the sole of the left foot, over the abductor hallucis muscle, following the guidelines set by Boucsein (1992). The usual sites on palmar side of the subject's non-preferred hand were not used in order to avoid movement artefacts, and because of the need for participants to use both hands. Before attaching the electrodes, the skin was cleaned with a low-alcohol detergent. A constant voltage of 0.6V was applied across the electrodes, and the signal was low-pass filtered with a cutoff at 10 Hz. Due to low quality the data of two participants were excluded from the analyses.

2.5 Psychological measurements

2.5.1 Background variables

The participants were divided into high and low groups based on the background variables. The groups were created as follows: the sample was divided on the median of age and computer use (hours per week). High gaming frequency group included respondents who reported playing digital games at least every other day. High FPS gaming frequency group was defined differently, to include respondents who reported playing at least every week. The rationale was that it is likely that people do not normally play games from one genre only, so a lower frequency cutoff was justified. High FPS skills group included respondents who reported to possess average skills or better (4 or 5 on scale from 1 to 5). High FPS attitude group included respondents who rated their liking of FPS games to "I like FPS games" or "FPS games are my favorite game type" (4 or 5) on scale with a range of five. High FPS favorite group included respondents who rated the FPS games as favorite or second favorite game genre among eleven possibilities. High Halo experience group included respondents who reported having played Halo single-player game previously more than half-way through the campaign. This resulted in very unequal group sizes, but was the only feasible division.

2.5.2 Flow State Scale (FSS)

The Flow State Scale is a 36-item questionnaire created by Jackson and Marsh (1996) to measure flow. It consists of nine subscales, each containing four items. The items are rated on a 5-point scale, ranging from 1 (strongly disagree) to 5 (strongly agree). Although there is no evidence of validity or reliability of FSS in the current context (digital gaming), it is the only instrument available which has been tested and used beyond the study of its initial publishing, and which does not rely extensively on the condition of balance between challenge and skills.

FSS was translated into Finnish by the author (see appendix B). Cronbach's alpha coefficient was calculated for the items, representing an acceptable reliability (α = .77). The questionnaire was delivered after the gaming session.

2.5.3 Valence and arousal ratings

Emotional adjectives presented by Russell and Mehrabian (1977) were used to gather the valence and arousal self-report ratings. Participant assessed his emotional state by choosing a number on a scale from 1 to 7, presenting a continuum of two opposing adjectives in the ends of the scale. Some examples of the adjective pairs are “active – passive” (arousal), “drowsy – lively” (arousal), and “happy – unhappy” (valence). The arousal scale consisted of five and the valence scale of six items. The adjectives were rated before and after the gaming session. Alphas for these scales were .76 for arousal and .83 for valence before the gaming session, and .80 and .79, respectively, after the gaming session.

2.6 Statistical methods

All statistical analyses were performed using SAS Enterprise Guide 3 (version 3.0.1.396) software (SAS Institute Inc., Cary, NC, USA). Valence and arousal self-report ratings were used as delta variables; ratings before the game session were subtracted from ratings after the game, to take account of the differences in initial values. Physiological measures were converted to delta scores by subtracting the mean of the last two baseline minutes from the means of the appropriate periods. All analyses concerning physiology were conducted with these delta scores.

3 Results

3.1 FSS

The overall FSS scores of the sample were high, with no participant’s score under 2.5 on scale from 1 to 5. Mean of all participants’ FSS scores was 3.76 (with standard deviation of 0.46); the minimum was 2.53 and maximum was 4.5.

The construct validity of FSS was examined by checking if the associations between the FSS score and the background variables and self-report affective ratings were in line with general characteristics usually attributed to flow (Csikszentmihalyi, 1990). Two-tailed independent samples t-tests were used to compare FSS scores of high and low groups by background variables. *F*-tests were used to verify the equality of variances assumption, and no variances were unequal.

The results of the t-tests are shown in the table 1. Demographics of age and computer use did not have a significant relationship with FSS score. The associations of FSS score to FPS gaming frequency ($p < .01$) and FPS favorite ($p < .05$) were significant. Effect sizes of these differences were large (Cohen's *d* = 1.18) and medium (*d* = 0.76), respectively. There were no other significant relationships between background variables and the FSS score.

Table 1.
Number of observations, means, and standard deviations of FSS scores by the low and high groups of background variables

	Low			High				
grouping variable	N	Mean	(sd)	N	Mean	(sd)	t(30) value	d
Age	17	3.68	(0.51)	15	3.89	(0.37)	1.30	
Computer use	15	3.7	(0.44)	17	3.84	(0.47)	0.89	
Gaming frequency	16	3.66	(0.45)	16	3.89	(0.44)	1.49	
FPS gaming frequency	14	3.51	(0.47)	18	3.98	(0.32)	3.32 **	1.18
FPS skills	11	3.64	(0.43)	21	3.85	(0.46)	1.23	
FPS attitude	9	3.57	(0.48)	23	3.86	(0.43)	1.65	
FPS favorite	18	3.62	(0.49)	14	3.98	(0.32)	2.42 *	0.76
Halo experience	26	3.71	(0.46)	6	4.06	(0.31)	1.78	

*p < .05, **p < .01

The self-reported valence and arousal ratings were correlated against the FSS score. The valence rating was significantly correlated with FSS score ($r = .60$, $p < .001$), whereas correlation between arousal and FSS score was not significant ($r = -.26$). The explanatory power of former correlation was 36%.

3.2 Physiological variables and flow

The association between flow and physiological variables was examined. A regression analysis with backward elimination method was conducted with FSS score as dependent variable and the physiological reactivity scores during the two periods (game period I and game period II, separately) as explanatory variables. Significance level of greater than 0.1 was used as the elimination criterion.

Regression analysis revealed no linear combination of delta scores of the physiological measurements associated with the FSS score. In case of both game periods the backward elimination procedure left only one variable to the model. The model with CS as the only variable was significantly and negatively associated with the FSS score, β = -1.72, $F(1,30) = 6.18$, $p < .05$, and β = -1.48, $F(1,30) = 4.82$, $p < .05$, for period I and period II, respectively. Explanatory power (adjusted R^2) of these models was 14.3% and 11.0%, for period I and period II, respectively.

To inspect the independent contribution of the physiological measurements to the FSS score the correlations were calculated (table 2). No correlation between the FSS score and the physiological measures, excluding CS on both game periods, exceeded .20 or approached significance. Therefore it was concluded that only a part of the hypothesis was supported by the data.

Further, the connections with the valence and arousal self-report ratings and the physiological variables (Lang et al., 1993) were examined by calculating the correlations. Neither the correlations between the facial EMG measures and the valence ratings, nor between SCL and arousal ratings, nor any other combinations, were significant or close to significance (table 3).

Table 2.
Correlations between physiological variables and FSS score (N = 32)

	r	r^2
CS period I	-.41*	0.17
ZM period I	-.05	
OO period I	.20	
SCL period I	.00	
CS period II	-.37*	0.14
ZM period II	-.03	
OO period II	.20	
SCL period II	-.17	

*p < .05

Table 3.
Correlations between valence and arousal self-report ratings and physiological variables (N = 30)

	valence rating		arousal rating	
	r	p	r	p
CS, period I	-0.11	.58	-0.03	.89
ZM, period I	-0.02	.91	0.01	.95
OO, period I	-0.27	.15	0.06	.74
SCL, period I	0.01	.95	0.15	.44
CS, period II	-0.07	.72	-0.05	.80
ZM, period II	-0.02	.90	-0.01	.97
OO, period II	-0.25	.19	0.07	.72
SCL, period II	-0.01	.95	0.20	.30

4 Discussion

The purpose of this study was to examine whether flow could be studied with psychophysiological methods. Previous research has established facial EMG measures to index emotional valence and skin conductance measures to index emotional arousal (Lang et al., 1993). Flow is supposed to be a state of high positive valence and high arousal (e.g., Csikszentmihalyi, 1990; Ellis et al., 1994), and digital games have been identified as elicitors of flow (e.g., Asgari, 2005; Choi & Kim, 2004). It was therefore hypothesized that those who report that more flow occurred during a digital gaming session would also have higher levels of valence and arousal as measured by physiological indices.

The hypothesis gained partial support from the data. Facial EMG activity over corrugator supercilii (CS, a muscle used in frowning) was the lower the higher the subject had reported his experience of flow, suggesting high positive valence (Lang et al., 1993). However, contrary to hypothesis, EMG activity over zygomaticus major (ZM) and orbicularis oculi (OO), which would also indicate high positive valence, was not found to have a relationship with flow in this sample. Similarly, high skin conductance level (SCL), indicating high arousal (Dawson et al., 2000), did not have an association with high flow.

Low CS activity is associated with high positive valence, but more importantly, it corresponds to low negative valence (Bradley, 2000; Lang et al., 1993). Although the association of flow and low negative valence has not been explicitly suggested, it is consistent with the literature. From the seminal writings of Csikszentmihalyi (1975) to recent papers, flow has been considered as an enjoyable experience or experience of satisfaction (see also Csikszentmihalyi & Csikszentmihalyi, 1988). Flow studies have also assessed feelings successfully with bipolar scales ranging from positive to negative (e.g., Ellis et al., 1994; Novak et al, 2000), thus assuming that flow, as an experience of high positive valence, is also associated with low negative valence. Low negative valence points to this “absence of unpleasantness”.

Following the reasoning above, the lack of association between flow and positive valence indices, ZM and OO, was unexpected. As CS is considered a better index of negative valence than ZM is of positive valence (Bradley, 2000), it is possible that the changes in ZM are not great enough to stand out in tonic reactivity of as long as forty minutes. Furthermore, the ZM activity does not correspond only to positive valence, but also highly negative stimuli result in higher ZM activity, compared to neutral stimuli (Lang et al., 1993). This may have confounded the results as the game period is also expected to contain negatively valenced experiences, such as frustration and dissatisfaction due to failure.

Averaging a long period of time may similarly result in problems with OO measures. The studies that have associated it with pleasure have used phasic reactions to single stimuli (Ekman et al., 1990; Jäncke, 1994), but it is not known what the relationship between tonic OO activity and valence is. It may be that responses from spontaneous eye blinks that are present in long-term OO activity hide the more subtle changes due to valence. It has been also shown that the magnitude of startle reflex (eye blink measured over OO) is inversely related to valence of viewed stimuli (Lang, 1995). There is no data on if this applies also to spontaneous eye blinks, but in case it does, it is notable that the potential effect of valence on OO activity would be the opposite of what was predicted here.

There was no association between self-reported valence and EMG measures. This may be due to reasons stated above, but another possibility is the bipolarity of the valence scale. It has been suggested that evaluation of affective states is better represented by unipolar negative and positive dimensions than by bipolar dimension with negative and positive in opposite ends (Cacioppo & Gardner, 1999; see also Tellegen, Watson & Clark, 1999, for another interpretation).

Arousal or excitement is explicitly or implicitly present in descriptions of flow (Chen et al., 1999; Csikszentmihalyi, 1975; Pace, 2004) and in used flow scales (Ellis et al., 1994; Novak et al., 2000), and arousal does not occur only momentarily, as valence does. The lack of relationship of reported flow and both SCL and self-reported arousal speak against the connection between flow and arousal. Still, there is a possibility that averaging over long period of time may have confounded the association between SCL and flow. Arousal occurs equally with negative and positive valence, so if those who reported lower flow had frequent negative experiences during the game, arousal would not distinguish between low and high flow.

The construct validity of Flow State Scale was found acceptable. Self-report valence rating was strongly positively related to reported flow (cf. Csikszentmihalyi, 1975). It is also commonly stated that flow is experienced by those who are familiar with the activity (Csikszentmihalyi, 1975; Kiewa 2001). In this sample, considering the FPS genre as a favorite one and playing FPS games often was associated with reporting higher flow scores on FSS. However, considering the genre merely liked and playing any games often were not associated with higher FSS scores, which suggests that dispositions to very specific facets of the activity (the genre of the game) may have a connection with how (and if) flow is experienced, in the case where the activity is not very simple (Chen et al., 1999). Additionally, no relationship between reported FPS skills and experienced flow was found. Although the range of reported skills was small in this sample, it nonetheless speaks against flow models where skills and challenge are separately assessed (e.g., Novak et al., 2000; cf. Ellis et al., 1994; Voelkl & Ellis, 1998).

Although basic psychometric properties of FSS were found acceptable, it is notable that as the formulations of the questions are designed to apply to sports environment, they are not necessarily interpreted the same way in current context. For example, one subscale of FSS assesses how countless repetitions make the well-done performance seem like automatic, as if the athlete does not consciously have to contribute to it. However, a digital game is an interactive activity where the environment and the agents in it contribute to create a different kind of experience every time. Even though it is a phenomenon that can occur during a game, the "automated" actions are short, irregularly occurring moments during a gaming session constantly changing pace. The same item, answered after a single athletic performance or a gaming session, may not contribute to the scale equally. The validity of FSS in digital gaming context likely suffers from these specific formulations that relate to original sports context.

The homogeneity and small size of the sample set limitations to the analyses. It has been suggested that flow is a rare occurrence (Csikszentmihalyi, 1975, 1990), but in this sample only two participants had a flow score lower than the midpoint of the scale. A sample larger and more balanced in regard to the flow-eliciting activity should provide more variation.

It is also worth noting that there is no previous data on emotional reactions during flow. All flow research until now has been conducted in retrospect, with questionnaires and interviews that necessarily interrupt flow even if used to gain knowledge about its process. Especially the assumption that there should be high positive valence during the whole process might be seen as groundless, as it is based on reports gathered after the process. It seems entirely possible that the enjoyment inherent to flow is strongly present only at the end of the process, when the person finally knows that the activity was not too difficult or too easy, but just challenging enough to be satisfied with one's performance. After all, if the person struggles with the activity for a time, but in the end it proves too difficult—would he then report that he experienced flow, as he was still "on the edge" of his skills before the end? The time dimension of flow is still unexplored.

4.1 Future directions

This study suggests that there is potential in psychophysiological measurements to flow research. The negative correlation with corrugator supercilii muscle and flow and the lack of relationship between skin conductance and flow should be studied further. Additionally, experiments examining more thoroughly the association of ZM and OO with flow should be conducted.

Cardiac measures should also be considered. Heart rate, for example, has been shown to relate to long-term attentional engagement, although it might have interpretative problems in complex situations (Berntson, Cacioppo & Fieldstone, 1996). Respiratory sinus arrhythmia (a measure of heart rate variability) has been suggested as a more reliable index of attention in these situations (Berntson et al., 1994; Porges, 2001). These measures were also taken in this study, but the data were subsequently decided to be abandoned due to poor quality resulting from technical difficulties.

A need for an instrument specifically designed to assess flow in human-computer interaction was also materialized. The scale used in this study was not created to be used outside the sports context. Future studies should examine how (and if) flow in human-computer interaction is different from original athletic experience, and a reliable and well-validated instrument should be created based on that data.

The most important benefit of the psychophysiological measurements in the case of flow studies, the possibility to examine the physiological changes in time, is yet to be explored. Some of the most important problems evident in this study might be solved if the time series of the data were examined. What is the process of flow like? Is there a positive affect present only at brief moments or for a longer time during some kind of "flow episode"? What is the role of arousal during flow? Are there some patterns of physiological activation present during flow, representing the flow state?

As an example a period of one participant's data was examined as a time series. Shown in figure 2, the period is from the beginning of the introductory period, and includes four minutes where the participant watches the starting movie of the game, and the time after that when the participant for the first time takes the control of the game character. Two things stand out: the difference of activation levels between the passive viewing period and active playing period, and the strong responses (spikes in EMG measures) in the active playing period, related to game events. This suggests that with proper methods activation states can be discerned from the data, and a state corresponding to flow might be found. Events could also be studied in relation to the time series, and not only as phasic reactions. The exact methods are still unclear, but the approach shows much promise.

4.2 Conclusions

Psychophysiological methods offer well-established indices for studying emotions. Using a digital game as a flow elicitor for a group of gamers these methods provided a look into the emotional concomitants of flow. The current explorative study showed for the first time that flow is associated with low negative valence, and that previously suggested (e.g., Ellis et al., 1994; Novak et al., 2000) connection between flow and arousal might not exist.

Future studies need to confirm the found associations, and examine further the associations that were left unclear. Other physiological measures should be included in these examinations, specifically cardiac measures. Larger and more diverse samples should be used. Other ways to analyze the physiological data should be explored, especially the time series approach.

For future game or human-computer interaction studies an instrument for assessing flow specifically in their context should be developed. Psychophysiological methods can be of help in this development: tapping into basic components of the flow experience these methods can validate that the assessed experience indeed includes enjoyment and focused attention. Additionally, reliably assessed flow may mean a powerful tool in game design discipline.

The promising results of this study highlight the potential that psychophysiological methods hold for flow research. Exploring the emotions and other processes relevant to flow provide a whole new approach to the old and confusing concept.

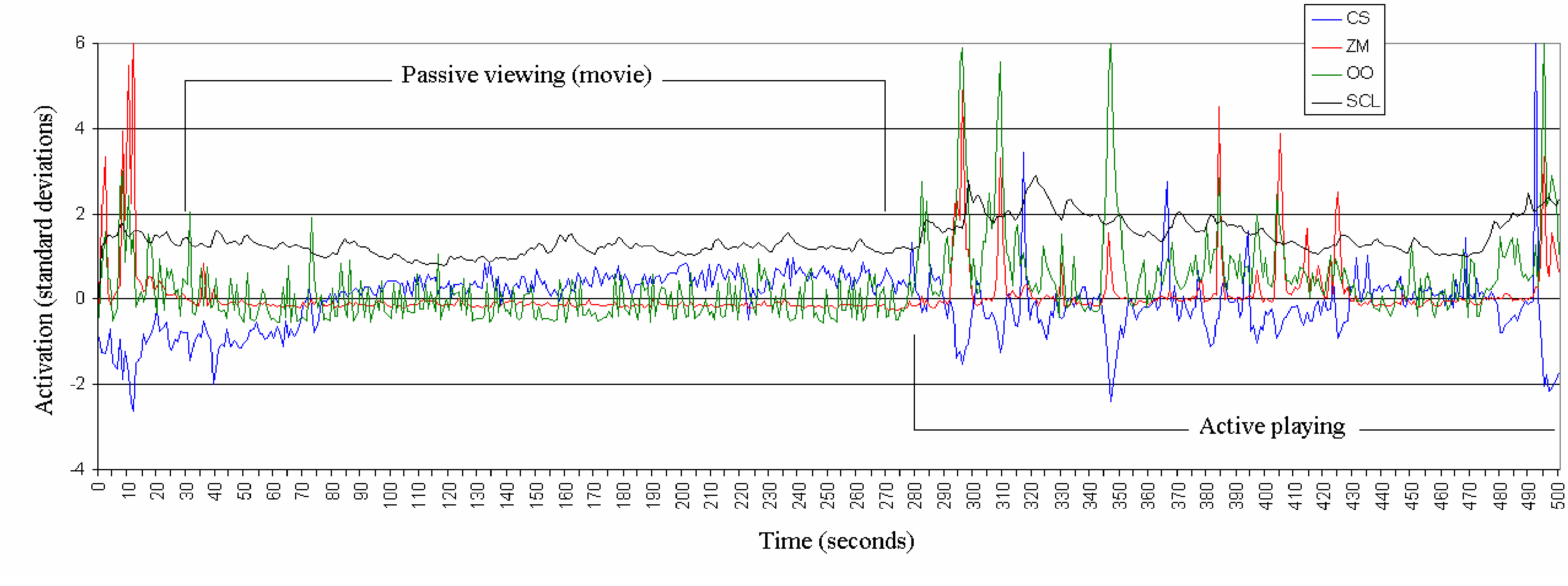

Figure 2.

Time series of corrugator supercilii (blue), zygomaticus major (red), and orbicularis oculi (green) EMG activity, and skin conductance level (black). The period in figure is the first 500 seconds (x-axis) of measurement in the introductory period. The y-axis is the amount of the activation on physiological channels in standard deviations (the physiological variables were standardized over the whole introductory period). The starting movie starts at 30 seconds and lasts for about 4 minutes to 270 seconds. There is a brief period where the perspective of the game is moved to first-person view, but when the player can't yet move. The player controls his character for the first time at 280 seconds. After that the player can actively participate in the game. Note the difference in activation on the left (passive viewing) and right (active playing) sides of the chart. Note also several strong responses to game events (for example, at about 298, 347, and 495 seconds).

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APPENDIX A: The nine flow characteristics

The flow in traditional sense is often broken down to characteristics, which are thought as common elements by which the flow is recognisable. They are (according to Csikszentmihalyi, 1990) the following:

1. *Balance of challenge and skills*. A person achieves flow experience when doing something on the very edge of one's skills. In the most used flow model, the four-channel model, flow occurs only when both challenges and skills are in balance but above certain level (i.e. high challenge – high skills).
2. *Clear goals*. The activity need not be goal-oriented per se, but it must be possible to set targets that are clear-cut and challenging enough the whole way to the end. The goals must be possible to attain, but not too easily, and set so that they don't interfere with each other (as a series of subgoals on a way to main goal).
3. *Unambiguous feedback*. While knowing every exact step during the activity, one must also be able to assess exactly when she is on the path and when missing the step. If there is no feedback or if it is unclear or delayed, a person loses the sense of control as she cannot evaluate what difference her actions make, what should be done otherwise to improve performance and what should be avoided.
4. *Merging of activity and awareness*. One does not think of mundane things like financial problems or even note one's surroundings, but all the concentration is focused on the task at hand and the activity becomes all that matters. This is easily noted by others in that it is difficult to get the attention of the person.
5. *Distorted sense of time*. When concentrating on the task, the awareness of time is lost as well. Probably the most commonly recognized characteristic of flow, losing the track of time is typical in highly involving activities.
6. *Loss of self-consciousness*. People report this characteristic as "becoming one with the activity", that is, not seeing themselves as separate entities during the activity but as an internal part of the process. If a professional athlete can make self-evaluations like "I hope my girlfriend would've seen that", he is being aware of oneself as a performer and is not concentrated solely on the activity.
7. *Sense of control*. The sense of control does not refer to feeling of being strongly in control but to forgetting the issue of control altogether. One feels the activity to be completely effortless, almost automatic process, where no issues of control, performance, self or (in most occasions) time are relevant.
8. *Feeling of enjoyment*. The whole process is experienced as highly enjoyable.
9. *Activity becomes autotelic*. The activity becomes important per se, not as a means to some external goal.

In contemporary research these have been categorized further as conditions or what is needed to achieve flow state (1-3), characteristics or what is it like to be in flow (4-7), and outcomes or what results of being in flow (8 & 9). (e.g. Chen et al., 1999)

APPENDIX B: Flow State Scale

Flow State Scale by Jackson & Marsh (1996), translated by the author.

# Q	Challenge-skills balance	Translation to Finnish
1	I was challenged, but I believed my skills would allow me to meet the challenge	Pelaaminen oli haastavaa, mutta uskoin että taitoni riittäisivät vastaamaan haasteeseen
10	My abilities matched the high challenge of the situation	Kykyni sopivat pelin tarjoamaan haasteeseen
19	I felt I was competent enough to meet the high demands of the situation	Tunsin olevani tarpeeksi kykenevä vastaamaan pelin vaatimuksiin
28	The challenge and my skills were at an equally high level	Haasteet ja taitoni vastasivat toisiaan
	Action-awareness merging	
2	I made the correct movements without thinking about trying to do so	Tein oikeat liikkeet ajattelematta että yrittäisin tehdä niin
11	Things just seemed to be happening automatically	Asiat vain näyttivät tapahtuvan itsestään
20	I performed automatically	Toimin automaattisesti
29	I did things spontaneously and automatically without having to think	Tein asioita spontaanisti ja automaattisesti ajattelematta
	Clear goals	
3	I knew clearly what I wanted to do	Tiesin selvästi mitä tahdoin tehdä
12	I had a strong sense of what I wanted to do	Minulla oli selvä käsitys siitä mitä tahdoin tehdä
21	I knew what I wanted to achieve	Tiesin mitä tahdoin saavuttaa
30	My goals were clearly defined	Omat tavoitteeni olivat minulle selkeät
	Unambiguous feedback	
4	It was really clear to me that I was doing well	Oli oikein selvää että pärjäsin pelissä
13	I was aware of how well I was performing	Olin selvillä siitä kuinka hyvin pärjäsin
22	I had a good idea while I was performing about how well I was doing	Minulla oli selkeä käsitys pelin aikana siitä kuinka hyvin pärjäsin
31	I could tell by the way I was performing how well I was doing	Tiesin yksittäisessä tilanteessa kuinka hyvin pärjäsin koko pelissä
	Concentration on task at hand	
5	My attention was focused entirely on what I was doing	Huomioni oli kokonaan kohdistunut siihen mitä tein
14	It was no effort to keep my mind on what was happening	Oli vaivatonta pitää huomioni tapahtumissa
23	I had total concentration	Olin täysin keskittynyt
32	I was completely focused on the task at hand	Huomioni oli täysin kiinnittynyt meneillään olevaan tilanteeseen
	Sense of control	
6	I felt in total control of what I was doing	Tunsin hallitsevani tilanteen täydellisesti
15	I felt like I could control what I was doing	Tuntui että pystyin hallitsemaan sen mitä olin tekemässä
24	I had a feeling of total control	Koin täydellisen hallinnan tunnetta
33	I felt in total control of my body	Tunsin hallitsevani ohjausliikkeeni täysin

	Loss of self-consciousness	
7	I was not concerned with what others may have been thinking of me	En miettinyt mitä muut mahtoivat ajatella minusta
16	I was not worried about my performance during the event	En ollut huolissani suoriutumisestani pelin aikana
25	I was not concerned with how I was presenting myself	En huolehtinut siitä millaisen kuvan annoin itsestäni
34	I was not worried about what others may have been thinking of me	En ollut huolissani siitä mitä muut saattoivat ajatella minusta
	Transformation of time	
8	Time seemed to alter (either slowed down or speeded up)	Ajan kuluminen tuntui muuttuneen (hidastui tai nopeutui)
17	The way time passed seemed to be different from normal	Ajan kuluminen tuntui erilaiselta kuin tavallisesti
26	It felt like time stopped while I was performing	Pelatessa tuntui kuin aika olisi pysähtynyt
35	At times, it almost seemed like things were happening in slow motion	Ajoittain tuntui siltä kuin asiat olisivat tapahtuneet hidastettuina
	Autotelic experience	
9	I really enjoyed the experience	Nautin todella kokemuksesta
18	I loved the feeling of that performance and want to capture it again	Pidin tämän pelin pelaamisesta ja tahdon kokea sen uudestaan
27	The experience left me feeling great	Kokemus jätti todella hyvän tunteen
36	I found the experience extremely rewarding	Kokemus oli minulle erittäin palkitseva