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Understanding the psychophysiology of flow: A driving simulator experiment to investigate the relationship between flow and heart rate variability

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ABSTRACT

We present the results of an experimental investigation on the relationship between heart rate variability (HRV) and flow in adults exposed to computer-simulated tasks with different demand level manipulations: a balanced skill-demand level (fit) to induce flow, too high demands to induce anxiety, and too low demands to induce boredom. Eighteen participants were exposed to three simulated driving tasks that differed in their demand levels. During all tasks, the participants' heart rates were monitored and flow was measured after each task by means of a questionnaire. Our results show that high-frequency HRV (HF-HRV) and low-frequency HRV (LF-HRV) differed between the three experimental conditions and an increase in demand level caused a decrease in HF-HRV and LF-HRV. Furthermore, experiencing flow in a balanced skill-demand task was associated with a decreased LFHRV activity compared to being engaged in a task with too high demands (anxiety condition), in which higher levels of flow were related to moderate parasympathetic activity (HF-HRV) as well as to moderate baroreflex function (LF-HRV). Our results contribute to a better understanding of the psychophysiology of flow and further demonstrate how virtual environments such a driving simulator can be effectively used to investigate psychological constructs such as flow or anxiety.

1. Introduction

Flow is described as a mental state that individuals experience when completely engaged in an activity (Csikszentmihalyi, 1975, 1991). Perceptions reported by individuals who have experienced flow involve an increase in attention and concentration, an improved sense of control over the activity, and a loss of sense of time (Csikszentmihalyi, 1975, 1991). So far, flow has mainly been assessed with retrospective questionnaires that require an interruption of the respective activity and potentially disrupt the flow experience. This poses a threat to the accuracy and reliability of the measurements. Consequently, there is an increased interest toward the development of non-disruptive measures for flow (Nakamura & Csikszentmihalyi, 2009).

One promising approach to induce and assess flow without disrupting the experience is using physiological measures (Moller, Meier, & Wall, 2010). Physiological variables such as heart rate variability can be assessed without interrupting the activity and are suitable to represent a whole activity process. Meanwhile, there is a breadth of research investigating the physiological aspects of flow experience (de Manzano, Theorell, Harmat, & Ullén, 2010; Keller, Bless, Blomann, & Kleinböhl, 2011a; Peifer, 2012; Peifer, Schulz, Schächinger, Baumann, & Antoni, 2014; Peifer, Schächinger, Engeser, & Antoni, 2015). The ultimate goal of these research efforts is to contribute to the development of psychophysiological measures to assess flow and consequently contribute to a better understanding of the physiological patterns of flow experience.

This study investigates the relationship between flow and heart rate variability in an experimental setting that uses a virtual driving simulator game. Artificial environments such as computer games or simulators have been proven to be particularly suitable for investigations on psychological constructs such as flow or stress (Chanel, Rebetez, Bétrancourt, & Pun, 2008).

1.1. Flow theory

Flow is defined as a pleasant state of absorption and an optimal experience during a challenging activity (Csikszentmihalyi, 1975).

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According to Csikszentmihalyi (1975, 1991), experiencing flow in an activity has three requirements. First, the activity needs clear goals. Individuals need to know what to do and when to do it. Second, the activity must provide clear and immediate feedback. Third, the demands of an activity must be in balance with the individuals' skill level. Csikszentmihalyi (1975, 1991) further listed components of flow experience that concern the individuals' perceptions. Perceptions reported by individuals who have experienced flow are: an increase in attention and concentration, an improved sense of control over the activity, a loss of sense of time, reduced self-consciousness, autotelic experience, focus on task-relevant information and fading out of task-irrelevant stimuli, and merging of action and awareness (Csikszentmihalyi, 1975, 1991). These perceptional components can appear independently from each other but altogether create the flow experience.

According to the flow-channel model (Fig. 1), the ideal condition to promote flow is to present individuals with a task or situation that they perceive as challenging but accomplishable by means of their own skills (optimal challenge–skill balance) (Csikszentmihalyi, 1975). Under these circumstances, individuals have the perception of control over the task and become totally absorbed in the activity. The importance of the perceived fit between skill and task demands for experiencing flow was also empirically supported by correlational studies (Jackson & Marsh, 1996; Moneta & Csikszentmihalyi, 1996; Schiefele & Roussakis, 2006) and experimental research (Eisenberger, Jones, Stinglhamber, Shanock, & Randall, 2005; Engeser & Rheinberg, 2008; Keller & Bless, 2008; Keller, Ringelhan, & Blomann, 2011b; Keller et al., 2011a; Rheinberg & Vollmeyer, 2003). If the demand level of a task exceeds individuals' skill levels, they appraise the activity rather as a threat or feel anxious. In contrast, if the skill levels of individuals exceed the demand level of a task, they are more likely to feel bored. Rheinberg and Vollmeyer (2003) demonstrated that flow can be manipulated experimentally by presenting tasks with different difficulty levels. According to their results, highest flow levels were reported during tasks with moderate difficulty levels, and lowest flow levels were observed during too easy and too difficult levels. Rani, Sarkar, and Liu (2005) also provided empirical support for the flow-channel model. In their study, the authors used different difficulty levels of a videogame to induce boredom, flow, and anxiety. Only when the players' skill and demand levels matched, did individuals report a sense of flow. Computer games, simulators, or online learning platforms have been shown to be particularly suitable to meet these requirements

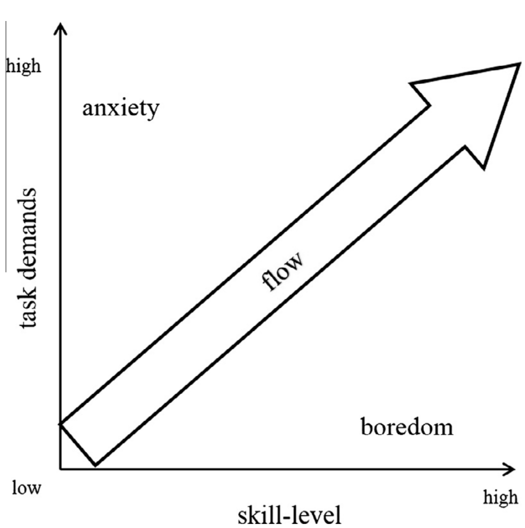

Fig. 1. Flow-channel model (adapted from Csikszentmihalyi (1975)).

and foster the experience of being actively engaged (Chanel et al., 2008; MacDowell & Mandler, 1989). Some properties of computer games make them generally useful for investigations on psychological theories and understanding physiological phenomena (van Reekum et al., 2004).

The flow-channel model (Csikszentmihalyi, 1975) can be related to Lazarus' transactional-stress model (Lazarus & Folkman, 1984). Likewise, it is assumed that when individuals' resources are insufficient to cope with a personally relevant situation, stress (or anxiety sensu Csikszentmihalyi) occurs. On the contrary, when resources meet the situational demands, individuals experience challenge as a pleasurable state. Csikszentmihalyi (1991) stated that flow can be experienced in stressful events if the task or activity is evaluated as a challenge (Peifer, 2012; Peifer et al., 2014). In contrast to the flow-channel model, the transactional-stress model also makes assumptions regarding physiological characteristics. The latter relates stress to physiological arousal, in particular to increased cardiovascular activity. Due to the conceptual similarities between stress and anxiety, we can expect that anxiety is associated with the same physiological characteristics as stress. Consequently, flow (placed between boredom and anxiety in the flow-channel model) should be associated with moderate physiological arousal. Thus, flow should be highest during moderate and lowest during high or low physiological arousal (Peifer, 2012; Peifer et al., 2014). This suggests an inverted u-shaped function between these variables. There are a several indicators for physiological arousal; however, we will focus on heart rate variability (HRV), which is the variation in the time interval between two successive heartbeats.

1.2. Psychophysiology of flow

Regarding physiological processes, flow has so far been associated with an increased release of cortisol (Keller et al., 2011a; Peifer et al., 2014, 2015) and an activation of the autonomic nervous system (ANS) (de Manzano et al., 2010; Keller et al., 2011a; Peifer et al., 2014). Bruya (2010) described flow as a state of effortless attention that arises through an interaction between positive affect and high attention, in which both the sympathetic and the parasympathetic system are activated (Peifer, 2012). In sum, flow is a state of arousal accompanied by a state of joy.

However, flow has also been linked to strain-inducing tension and increased mental load (Keller et al., 2011a). In an experimental study, participants played a quiz game with different difficulty levels (easy, skill-matched, and difficult) while their heart rates were monitored. The physiological responses of participants exposed to a balanced skill-demand task showed similarities to the physiological responses during stress regarding the release of salivary cortisol and HRV (Keller et al., 2011a). Their study reported an increase in involvement and showed a decrease of the HRV measure compared to participants in the other conditions. Based on these observations, the researchers argued that flow is associated with an increase of sympathetic activity and hypothala mic–pituitary–adrenal axis activity. However, flow scores were neither correlated with HRV nor with cortisol level, which would be necessary to support a relationship between flow and a physiological variable. Instead, a match between the participants' skill and demand levels was equated with flow experience. Contrary to the results of Keller et al. (2011a), Peifer et al. (2014) found a positive linear relation between HRV and flow experience in a stressful task, in which participants with higher HRV experienced higher levels of flow. However, Peifer and colleagues did not experimentally manipulate the skill-demand level. They rather first induced stress by means of the Trier Social Stress Test (Kirschbaum, Pirke, & Hellhammer, 1993) before participants were engaged with a computer program. Thus, flow and stress were