Computers & Education 79 (2014) 69–100

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

Flow, social interaction anxiety and salivary cortisol responses in serious games: A quasi-experimental study

Cyril Brom [a, *], Michaela Buchtová [a, b], Vít Šisler [a], Filip Děchtěrenko [a], Rupert Palme [c], Lisa Maria Glenk [d]

[a] Faculty of Mathematics and Physics, Charles University in Prague, Malostranske Namesti 25, 11800 Prague, Czech Republic
[b] Faculty of Arts, Charles University in Prague, U kříže 8, 15800 Prague 5, Czech Republic
[c] Institute of Medical Biochemistry, Department of Biomedical Sciences, University of Veterinary Medicine Vienna, Austria, Veterinärplatz 1, A-1210 Vienna, Austria
[d] Comparative Medicine, Messerli Research Institute, University of Veterinary Medicine Vienna, Medical University Vienna, University of Vienna, Austria, Veterinärplatz 1, A-1210 Vienna, Austria

A R T I C L E I N F O

Article history:
Received 7 March 2014
Received in revised form
17 June 2014
Accepted 1 July 2014
Available online 27 July 2014

Keywords:
Digital game-based learning
Flow
PANAS
Social interaction anxiety
Cortisol

A B S T R A C T

Serious games are supposed to instigate engagement and, in turn, improve learning. High engagement is frequently connected with a positive affective state and a high flow state. However, the alleged link between a learner's affective state, his/her flow state and learning outcomes has not been investigated in detail in the context of serious games. Even less information is available on how serious games may influence markers of physiological arousal. To fill this gap, participants of this exploratory study ($N = 171$) played one of the six different serious game-based treatments, while we measured their affect, flow, cortisol secretion and learning achievement. The treatments were supposed to generate different levels of engagement and cortisol responses, because some of them were designed for a single user, while others were team-based, featuring so-called social-evaluative threat (ST) components. Our results revealed that flow was positively related to positive affect and negatively to negative affect. While flow and positive affect were related to learning gains, almost no relationship between either of these three variables and cortisol levels was found. Negative affect and cortisol were elevated in social interaction anxious males in team-based conditions. This study contributes to the limited body of research on the relationship between engagement and learning in serious games. We provide new perspectives on the relationships between flow, positive/negative affect and cortisol. Our findings highlight the fact that team-based serious games with ST components may have adverse effects on learners, particularly males, with high social interaction anxiety.

1. Introduction

Digital game-based learning (DGBL) presents a new instructional technology with many alleged advantages in the context of a formal schooling system. Digital games for education, oftentimes called *serious games*, have been gradually coming into use by schools (Huizenga, Admiraal, & Ten Dam, 2013; Wastiau, Kearney, & den Berge, 2009). The number of research studies investigating serious games' usage, learning effects and the attitudes of different stakeholders toward games' adoption in formal education is growing (e.g., Connolly, Boyle, MacArthur, Hainey & Boyle, 2012; De Grove, Bourgonjon, & Van Looy, 2012; Girard, Ecalle, & Magnan, 2012; Hays, 2005; Sitzmann, 2011; Tobias, Fletcher, Dai, & Wind, 2011; Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013).

---

* Corresponding author. Faculty of Mathematics and Physics, Charles University in Prague, Room 312, Malostranske Namesti 25, 11800 Prague, Czech Republic. Tel.: +(420) 221 914 216; fax: +(420) 221 914 281.
E-mail addresses: brom@ksvi.mff.cuni.cz (C. Brom), michaela.buchtova@ff.cuni.cz (M. Buchtová), vsisler@gmail.com (V. Šisler), filip.dechterenko@gmail.com (F. Děchtěrenko), rupert.palme@vetmeduni.ac.at (R. Palme), lisa.glenk@vetmeduni.ac.at (L.M. Glenk).

http://dx.doi.org/10.1016/j.compedu.2014.07.001
0360-1315/© 2014 Published by Elsevier Ltd.

One of the key alleged advantages of the DGBL approach is that games could motivate learners via play and this, in turn, could improve learning (*Motivation → learning* hypothesis). This idea has been articulated by many researchers (e.g., Garris, Ahlers, & Driskell, 2002; Hays, 2005; Wouters et al., 2013; see also Habgood & Ainsworth, 2011; Malone, 1981; Malone & Lepper, 1987). However, despite a large body of research on disentangling the link between emotions and cognition (e.g., Eysenck & Keane, 2010, Ch. 15; Robinson, Watkins, & Harmon, 2013) and emotions and memory/learning (e.g., Anderson, 2009; Reisberg & Hertel, 2003; but see also Pekrun, 2005), the issue of mere establishing a clear link between games' motivational factors and students' learning gains has not been sufficiently addressed in the DGBL context. First, as suggested in an older review of educational game studies (Hays, 2005; p. 47), games may be inherently more engaging than conventional instruction methods but that may not necessarily result in better learning outcomes. A game's motivational factors, deemed to promote learning by increasing the learner's interest and making him/her invest more energy into learning, may also serve as distractors and thereby reduce learning gains; i.e., a trade-off (cf. van Dijk, 2010; Mayer, 2009; Moreno, 2005; Um, Plass, Hayward, & Homer, 2011). Second, DGBL studies only rarely report correlations between affective and knowledge measures. The most recent meta-analysis, and probably also the most rigorous so far (Wouters et al., 2013), indicated that games are slightly better for learning, when compared to traditional types of instruction, as well as slightly more motivating, but the latter finding was only marginally significant.[1] In addition, the relation between the affective and cognitive dimensions was not elucidated. Only a handful of studies has directly investigated this relationship in the DGBL field (e.g., van Dijk, 2010; Ritterfeld, Shen, Wang, Nocera, & Wong, 2009; see also Habgood & Ainsworth, 2011) or in the field of multimedia learning (e.g., van der Meij, 2013; Plass, Heidig, Hayward, Homer, & Um, 2014; Um et al., 2011). Finally, classical measures – mostly questionnaires with Likert items, often self-constructed and administered after the intervention – were sometimes questioned due to low validity (e.g., Wang et al., 2008, p. 110; Wouters et al., 2013, p. 261).

Recent research has attempted to identify transient affective states experienced by learners during a learning task (e.g., Craig, Graesser, Sullins, & Gholson, 2004; Elliot & Pekrun, 2007; Hussain, AlZoubi, Calvo, & D'Mello, 2011). These states often include anxiety, boredom, confusion, frustration, curiosity, delight and engaged concentration (Baker, D'Mello, Rodrigo, & Graesser, 2010; D'Mello & Graesser, 2012; Lester et al., 2013). Engaged concentration, also called state engagement, has so far not been operationalized precisely, but it is tentatively linked to mild generalized positive affect and certain components of flow state; such as focused and intense attention.[2] Affect has a complex structure, but generalized positive and negative affect emerge as "two dominant and relatively independent dimensions" (Watson, Clark, & Tellegen, 1988, p. 1063). Flow state is often conceptualized as: a) highly focused concentration on the activity; b) coherence of the activity; c) balance between one's skills and the activity's demands; d) deep sense of control; e) distorted temporal experience; and f) a feeling that the activity is innately rewarding (Csikszentmihalyi, 1975; cf. Engeser & Rheinberg, 2008; Keller, Bless, Blomann, & Kleinböhl, 2011). Even though the concept of engaged concentration originated in the field of tutoring systems (see Baker et al., 2010), it is also highly relevant for the DGBL field, because it is arguably one of the most crucial affective states instigated by playing games. In this study, we will assess it indirectly by measuring generalized positive affect and flow. Notably, positive affect and flow are correlated when participants are engaged in interesting tasks (Brom, Bromová, Děchtěrenko, Buchtová, & Pergel, 2014; Rogatko, 2009). Both flow and positive (as well as negative) affect can be assessed by standardized research instruments, such as the Flow Short Scale (Rheinberg, Vollmeyer, & Engeser, 2003) and the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988), respectively. Yet only few DGBL studies have investigated learning effects, flow and positive–negative affective states all at the same time.

Digital games frequently involve competitive or challenging tasks that strongly influence players' engaged concentration. It is often assumed that this influence is generally positive; however, from a psycho-physiological perspective, these tasks may be inherently stressful for some players. Both physical and psychological stress can activate the hypothalamus–pituitary–adrenal (HPA) axis, resulting in triggered secretion of the glucocorticoid hormone cortisol (Wingfield & Sapolsky, 2003). Mediating cascading levels of physiological arousal, the primary function of cortisol is to help an organism adapt to its environment. Increases in cortisol have been linked to stressful experiences that require an individual to cope with internal or external demands (Chrousos, 2009). Because challenging tasks in games are supposed to increase players' engaged concentration (i.e., positive affect and/or flow state) and certain challenging tasks are also connected to elevated cortisol (Dickerson & Kemeny, 2004), we can conjecture that engaged concentration may be connected to elevated cortisol too. Notably, it has also been suggested that cortisol levels vary with positive and negative outcomes on learning and memory (Roozendaal, 2002). Could cortisol play a role in linking engaged concentration and learning?

Over the past decades, analysis of salivary cortisol in response to a stressor has established itself as a state-of-the art method in psychophysiological research (Hellhammer, Wust, & Kudielka, 2009). In humans, cortisol secretion follows a typical circadian pattern, with increasing levels in the early morning hours and a peak at the time of waking. Afternoon is perhaps the best time for conducting laboratory research that includes cortisol sampling (Dickerson & Kemeny, 2004). Nevertheless, if confronted with a powerful stimulus (i.e., stressor), cortisol levels sampled during any part of the day can even rise above those of the circadian peak (Kudielka, Hellhammer, & Würst, 2009). Saliva sampling is non-invasive and can be carried out easily under natural conditions outside of a laboratory (Inder, Dimeski, & Russell, 2012), including during game playing.

In general, past research on (non-educational) digital games has previously incorporated cortisol measurements. For instance, the cortisol-modulating effects of built-on music during video game playing have been described by Hébert, Béland, Dionne-Fournelle, Crete, and Lupien (2005). Violent content in video games has been controversially linked to subsequent increases in salivary cortisol (Hossini, Rezaeeshrazi, Salehian, & Dana, 2011; Ivarsson, Anderson, Akerstedt, & Lindblad, 2009; Oxford, Ponzi, & Geary, 2010). Stressful video games can decrease reaction time in the accomplishment of attentional tasks in absence of a concomitant increase in salivary cortisol levels

---

[1] The second recent meta-analysis (Sitzmann, 2011) reported similar findings, as concerns the cognitive dimension, but noted that "the scarcity of [comparative] research … precludes an empirical test of the effect of simulation games on post-training motivation, effort, and trainee reactions". (p. 495). In studies with randomization, the positive effect of games on learning gains significantly diminishes in Wouters et al. (2013) but not in Sitzmann (2011). These two meta-analyses have minimal overlap in primary literature.

[2] The relationship between positive affect and flow state, on the one hand, and engaged concentration, on the other hand, was pointed out to us by Sidney D'Mello [email Correspondence from 9 March 2014].