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FlashReport

Physiological aspects of flow experiences: Skills-demand-compatibility effects on heart rate variability and salivary cortisol[☆]

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ABSTRACT

This research addresses flow theory according to which the compatibility of skills and task demands involved in an activity elicits flow experiences that render the activity intrinsically rewarding. Departing from correlational research, we applied experimental paradigms designed to test the impact of a skills-demands-compatibility on the emergence of flow in computerized tasks. On the one hand, the results from self-reports support the balance hypothesis and indicate that skills-demands-compatibility results in a pleasurable flow experience. On the other hand, the results also indicate that skills-demands-compatibility resulted in (a) reduced heart rate variability indicating enhanced mental workload, and (b) stress as indicated by relatively high levels of salivary cortisol. These results indicate that flow experiences combine subjectively positive elements with physiological elements reflecting strainful tension and mental load.

Introduction

Flow theory (cf. Csikszentmihalyi, 2000) holds that individuals experience a positive state of flow whenever they engage in skill-related activities and perceive a fit of skills and task demands (balance hypothesis). Flow is conceptualized as an experiential state characterized by (a) intensely focused concentration on the activity, (b) loss of reflective self-consciousness, (c) deep sense of control; (d) distorted temporal experience (hours seem like seconds); and (e) the activity feels inherently rewarding.

The concept of flow has a prominent status in positive psychology and the literature on flow advices individuals to seek and maximize flow experiences. However, flow experiences may have negative side effects. First, flow experiences potentially elicit an addiction to the target activity (e.g., online gaming) thereby leading to the neglect of other important (social) activities (Moody, 2001; Ng & Wiemer-Hastings, 2005). Second, the challenging and demanding character of flow activities may cause physiological changes that resemble those observable in situations in which individuals are overloaded by task demands. The present research addresses this latter question by relying on an experimental approach (for a discussion of the experimental approach see Keller & Bless, 2008; Moller, Meier, & Wall, 2010). Specifically, we investigated how skills-demands-compatibility influences heart rate variability (HRV, Experiment 1) and level of cortisol (Experiment 2) as established indicators of mental workload and stress, respectively.

Experiment 1

Prior research has consistently revealed that mental workload and information-processing demands are reflected in the level of HRV. Specifically, increases in workload have been associated with decreases in HRV (Fahrenberg & Wientjes, 2000; Hjortskov et al., 2004; Jorna, 1992; Mulder, 1992; Mulder, Mulder, Meijman, Veldman, & van Roon, 2000; Scerbo et al., 2001). Moreover, mental load is not only affected by task demands but also by individuals' involvement (MacKinnon, Geiselman, & Woodward, 1985)—which in turn constitutes a core element in flow theory.

To investigate the impact of skills-demands-compatibilities on HRV we created experimental conditions of "boredom" (skills exceeding demands), "fit" (skills matching demands), or "overload" (demands exceeding skills). We expected that both, the fit and overload conditions would elicit substantial task-related mental workloads and therefore that these conditions result in decreased HRV when compared to boredom conditions. Given that the fit condition is associated with high involvement, the decrease in HRV should be at least as strong – if not even more pronounced – as in the overload condition. We consider an experimental approach to flow a valuable research strategy although some flow theorists question this perspective (for a discussion, see Moller et al., 2010).

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Table 1
Indicators of the experiential state during task engagement (in Experiment 1) as a function of playing mode (varied within participants).

Playing mode	Boredom	Fit	Overload	*F*	*p*<
Dependent variable					
Perceived fit[a,b]	1.75 (0.71)	5.25 (0.71)	6.38 (0.74)	104.25	.001
Involvement index[a]	3.35 (1.22)	4.91 (1.21)	3.79 (1.37)	5.87	.02
Heart rate variability (adjusted for baseline)[c]	−2.30 (18.9)	−10.31 (17.2)	−5.83 (18.2)	4.85[d]	.03

Note. Figures in parentheses represent standard deviations.
[a] Assessed on seven point Likert scales.
[b] Response scale labeled (1) *too low* to (7) *too high*.
[c] Outlier case excluded.
[d] Test statistic based on ANOVA, with nonparametric confirmation of the main effect (Friedman test).

Method

Participants and design

Eight University of Mannheim students (4 women) received 2 Euros for participation and worked under three within-participant conditions: boredom, fit, and overload. After each of the three periods of task performance participants completed a questionnaire assessing different dimensions of flow and additional dependent measures described below.

Participants engaged in a computerized knowledge task. The questions were selected from the German version of a game based on the TV show "Who wants to be a millionaire?" (Jumbo Spiele®, 2000). Each question was presented with four response options and participants had to select one response within a limited time period (in the boredom condition there was no time limit).

In the *boredom condition*, the difficulty level was rather low (relative to participants' skill) and participants had no option to increase it. In the *fit condition*, the difficulty level was constantly adapted to each participant's performance level. If the participant successfully handled a certain number of tasks, the difficulty level was automatically increased by one step. If the participant failed a certain number of times, the difficulty level was decreased by one step. Thus, the difficulty level was constantly adjusted to realize a skills-demands-compatibility (see Keller & Bless, 2008, for empirical evidence on this approach). In the *overload condition*, the task was so difficult that participants were not able to handle it successfully. Skill-demands-compatibility was manipulated within participants (sequence: boredom, fit and overload; five minutes task activity in each setting).

Dependent variables

After each of the playing settings, participants responded to items designed to assess specific dimensions of experiences on response scales with endpoints labeled (1) *not at all true* and (7) *completely true*.

Involvement. Flow experiences are usually assessed by self-reports concerning the level of involvement (cf., flow state scale developed by Jackson & Marsh, 1996; sample item: "I was completely focused on the task at hand"). Accordingly, we assessed involvement as crucial component of the flow experience with a scale successfully employed in prior research (Keller & Bless, 2008) showing high internal consistency (alphas = .90, .95, .92).

Perceived skills-demands-compatibility was assessed with the item "Please indicate the degree to which the demands of the task were too low or too high for you" on a scale ranging from (1) *too low* to (7) *too high*.

Heart rate variability. HRV was measured on a beat-to-beat basis with a pulse watch recording RR-time intervals in milliseconds (©Polar RS800). Participants wore a transmitter fixed above the sternum with ECG-electrodes. After artifact-correction, the data were exported to the software 'Kubios HRV Analysis' (Niskanen, Tarvainen, Ranta-aho, & Karjalainen, 2002). As parameter for HRV, the 'root mean square of successive differences' (RMSSD; Allen, Chambers, & Towers, 2007; Malik et al., 1996) was calculated for 5 min time spans of the three experimental conditions. Baseline HRV data were also assessed in an initial phase where participants were instructed to rest for a moment (3 min) before they started with the experimental procedure. Differences in HRV (baseline values subtracted) between conditions were analyzed by ANOVA, with nonparametric confirmation of the main effect (Friedman test).

Results and discussion

Perceived fit

Participants perceived the task demands as too low in the boredom condition and as too high in the overload condition, with the fit condition falling in between (see Table 1). Contrast analyses revealed that participants scored significantly lower on the perceived fit measure when under boredom conditions, $t = 11.32$, $p < .001$, and significantly higher when under overload conditions, $t = 4.97$, $p < .001$, compared to fit conditions, thus reflecting a successful manipulation.

Involvement

Consistent with prior research, participants reported higher levels of involvement after task engagement under the fit condition compared to the non-fit conditions (see Table 1). Contrast analyses revealed a reliable difference between fit and overload as well as between fit and boredom conditions, $t = 2.28$, $p = .05$ and $t = 2.61$, $p < .04$. This pattern supports the balance hypothesis of flow theory and replicates previous findings using a within-participants design.

Heart rate variability

The data of one participant was excluded from further analyses because the HRV data differed markedly from the remaining sample and Grubbs' test (1969) for outlier detection reached significance (G = 2.07, p < .01). All other participants had a similar pattern of HRV time course over experimental conditions. The subsequent analysis revealed a significant main effect of condition (see Table 1), with highest HRV in the boredom condition reflecting lowest mental load. Post hoc comparisons attested higher HRV in the boredom than in the fit condition ($p < .05$), while the fit and overload conditions differed at trend-level significance ($p < .10$). Interestingly, this finding can be interpreted in different ways. Decreased HRV may reflect a particularly strong involvement under fit conditions, complementing self-report results which also show highest involvement under fit. However, the strong decrease in HRV under fit could also indicate mental strain that may result in mental fatigue which can be associated with lower performance in subsequent tasks (Ashcraft, 1998; Baddeley, 1983; Baddeley & Hitch, 1974).[1] Note that the

[1] Additional analyses revealed that the effect of the experimental manipulation on HRV remained basically unchanged when we controlled for self-reported involvement suggesting that HRV does not reflect participants' experienced level of involvement. We tested the proportion of the total effect of the treatment on the outcome variable RMSSD via mediation by flow following the logic outlined by Judd, Kenny, and McClelland (2001) performed with The R Package of Statistical Computing and the library "Mediation V2.1" (cf. Imai, Keele, Tingley, & Yamamoto, 2010). This analysis revealed that the proportion of the total effect could not be distinguished from 0 (proportion: −0.0912; 95% Quasi-Bayesian Confidence Intervals: −3.430, 4.201). This result seems to be more in line with the "negative" interpretation of our HRV findings.

findings are supported by recent research by De Manzano, Theorell, Harmat, and Ullén (2010) who found that higher levels of flow were associated with decreased HRV. Moreover, these authors found significant relations between flow and heart period, blood pressure, activity of the zygomaticus major muscle, and respiratory depth.

Experiment 2

To address the question whether skill-demands-compatibility is associated with physiological reactions indicative of straining tension, in Experiment 2, we assessed a physiological reaction which unambiguously indicates that individuals' biological system signals a problematic situation. Specifically, we assessed salivary cortisol which is considered one of the best indicators of physiological response to straining stimulation. Both, physical and psychological strain activates the hypothalamic-pituitary-adrenal (HPA) axis resulting in an increased synthesis of cortisol (Kirschbaum & Hellhammer, 1989, 2000). Particularly interesting in the present context is work by Mason (1968) who reported that personal involvement is a potent stimulus known to activate the HPA axis. This suggests that flow experiences – reflecting strong involvement – are likely to trigger increased cortisol levels. Also, the fact that engagement in challenging tasks such as public speaking (Bassett, Marshall, & Spillane, 1987) or airplane captains conducting multiple takeoffs and landings (Kakimoto, 1985) has been shown to result in elevated levels of cortisol suggests that the challenging condition of a skills-demands-compatibility may be associated with increased levels of cortisol.

Moreover, we addressed the fact that the flow experience is sometimes interpreted as reflecting nothing particularly special but rather a general experience of "having fun"—although flow theory highlights the fact that boundary conditions of flow explicitly distinguish this state from the experience of positive affect in general and from experiencing fun in a passive manner (e.g., observing a sunset). Therefore, we included a measure of positive affect (elated mood) to assess the impact of skills-demand-compatibility on this indicator. We expected no substantial effect on this general measure of positive affect as a challenging experience is likely to involve both enjoyable and discomforting aspects.

Method

Participants and design

61 male[2] University of Mannheim students received 7 Euros for participation in a study involving the computer game Tetris (game playing period of 15 min) and were randomly assigned to one of the conditions boredom, fit, and overload. The aim of the Tetris game is to arrange "falling" objects so that they constitute completely filled lines at the bottom of the playing field. The falling objects can be moved to the right or left and rotated in 90° steps with assigned keys on the keyboard (cf., Keller & Bless, 2008).

Dependent variables

Salivary cortisol. Cortisol samples were obtained using "Salivettes" (Sarstedt; Nümbrecht, Germany). They were prepared for biochemical analysis by centrifuging at 3000 rpm for 5 min. Salivary-free cortisol concentrations were determined employing a chemi-luminescence-assay with high sensitivity of 0.16 ng/ml (IBL; International GmbH, Hamburg, Germany). The first 2 cortisol samples were obtained as baseline measures before participants engaged in the task (at the outset of the study); afterward, sampling was continued with samples taken 20, 25 and 30 min after the game playing period.

[2] Women's endocrinological system is frequently affected by contraceptive drugs as well as the menstrual cycle which is why we worked with an all-male sample in this study.

Table 2
Indicators of the experiential state during task engagement (in Experiment 2) as a function of playing mode.

Playing mode	Boredom	Fit	Overload	*F*	*p*<
Dependent variable					
Perceived fit[a,b]	2.00 (1.17)	4.10 (1.38)	5.55 (0.95)	45.76	.001
Involvement index[a]	4.09 (1.54)	4.95 (1.13)	3.74 (1.51)	4.08	.03
Mood[c]	6.19 (1.51)	6.24 (1.21)	5.61 (1.33)	1.33	.28
Cortisol (nmol/L, adjusted for baseline)	5.27 (2.24)	7.53 (3.70)	6.97 (4.53)	4.19	.03

Note. Figures in parentheses represent standard deviations.
[a] Assessed on seven point Likert scales.
[b] Response scale labeled (1) *too low* to (7) *too high*; [c] Assessed on nine point Likert scales.

Mood. We assessed participants' mood with four items on 9-point scales with endpoints labeled *very bad–very good*, *unhappy–happy*, *sad–cheerful*, *depressed–serene* (alpha = .86).

Involvement. Task involvement was assessed with a six item scale (sample items read "I was deeply involved in the game" and "I did not realize how time was passing"; alpha = .90). The scale was positively correlated with the mood index, $r = .45$, $p < .001$.

Results

Perceived fit

Participants perceived task demands as too low under boredom and as too high under overload, with the fit condition falling in between (see Table 2). Contrast analyses revealed that compared to fit participants scored significantly lower on the perceived fit measure under boredom, $t = 5.68$, $p < .001$, and significantly higher under overload, $t = 3.95$, $p < .001$, reflecting a successful manipulation.

Mood

No effect of the experimental manipulation emerged on the mood index (see Table 2).

Involvement

Parallel to Experiment 1, the manipulation resulted in a significant effect on involvement (see Table 2). Contrast analyses revealed that involvement was highest in the fit condition relative to the overload and the boredom condition, $t = 2.77$, $p < .01$ and $t = 1.97$, $p = .05$.

Salivary cortisol

We submitted participants' cortisol levels (averaging across the three critical assessments following the experimental manipulations; Cronbach's alpha = .99) to an analysis of variance with baseline cortisol level as covariate. We observed high cortisol levels in participants under fit and overload conditions (see Table 2), reflected in a significant effect of the experimental manipulation. Contrast analyses revealed that participants under boredom showed lower cortisol levels than those under overload, $t = 2.07$, $p < .05$, and those under fit, $t = 2.80$, $p < .01$. Overload and fit conditions did not differ, $t < 1$. It seems remarkable that conditions eliciting a subjective flow experience can trigger physiological stress at a level even slightly higher than observed under conditions of overload.[3]

[3] In Study 2, the indirect effect (mediation) could not be established either. Even in analyses selectively comparing the boredom with the fit condition we observed no evidence supporting a mediational role of self-reported flow regarding the effect of the experimental manipulation on cortisol. In our view, this fractionation of physiological and self-report indicators is not too surprising given that a strong uncoupling of reportable and actual physiological activation has been well documented in social psychological research (cf. Cacioppo & Petty, 1983; Cacioppo, Tassinary, Stonebraker, & Petty, 1987).

General discussion

The present work extends previous research on flow experiences in various respects. The obtained findings bearing on distinct *physiological and hormonal aspects* of flow experiences are the first studies that experimentally address the physiology associated with flow experiences.[4] Results indicate that flow experiences represent a distinct state that can be identified not only with self-report data but also on physiological measures. Experiment 1 showed that participants reacted with decreased HRV under conditions of skills-demands-compatibility which indicates that they experienced a state of mental workload that can be interpreted as physiological evidence documenting deep involvement under conditions of skills-demands-compatibility.

Experiment 2 revealed that a skills-demand-compatibility can result in relatively high levels of salivary cortisol. This documents that a state of flow was associated with a physiological reaction indicating that participants' biological systems signaled a problematic situation. That is, flow experiences can be considered as involving straining tension and mental load from a physiological perspective. Of course, if one subscribes to the notion that stress can take on negative but also positive forms (eustress; Selye, 1975) the finding may be interpreted as an indication that participants experienced a *positive* form of stress (Selye, 1975). However, one would expect an elevated mood state if participants actually experienced a positive form of stress and we did not find empirical support for this notion. It is also noteworthy that eustress is typically referred to as a form of stress that is *healthy*. In our view, it is questionable whether increased levels of cortisol can be considered as healthy—in particular when they endure for extended periods. We strongly believe that an assessment of the physiological elements involved in flow experiences warrants further and systematic investigations. Specifically, complementing the current work which focused on short-term aspects, studies assessing physiological reactions during longer periods of flow (compared to boredom and overload) experiences would be particularly meaningful. Though we readily agree that flow experiences are important and worthwhile to peruse, the present findings emphasize the necessity to take a closer look at potential side effects.

Finally, the data concerning participants' mood state assessed in Experiment 2 indicate that it is not meaningful to interpret the flow experience merely as a state of "having fun" or "feeling good." The observed divergence in the effect that the skills-demands-compatibility manipulation exerted on the measures assessed in Experiment 2 suggests that experiencing a fit of skills and task demands is likely to trigger fairly specific experiential and physiological mechanisms that differentiate this state from other (positive) experiences.

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[4] Note that De Manzano et al. (2010) studied physiological aspects of flow (although not with an experimental design); Moller, Meier, and Wall (2010) reported on experimental work (but they did not address physiological parameters).