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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.