10 The Physiology of Effortless Attention: Correlates of State Flow and Flow Proneness

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When in flow, a person is highly concentrated and absorbed in an ongoing activity—yet, there is no subjective feeling of mental effort (Csikszentmihalyi 1990). The term *effortless attention* has been proposed for this type of attentive state to distinguish it from more well-studied states of high attention during mental effort (see, e.g., Bruya, Introduction, this volume). The main purpose of this chapter is to investigate whether high attention during flow is not only phenomenologically but also physiologically different from effortful attention. As a background, we first relate the concepts *flow* and *flow proneness* to current theories of emotion, attention, and expertise. Thereafter we survey the at present relatively small literature on psychological and physiological correlates of flow, and proneness for flow experiences, and examine whether it is in line with the view that attention during flow is distinct from attention during mental effort. We conclude with a brief discussion of how the psychophysiology of flow may explain links between flow and health.

The Flow State and Flow Proneness

Flow is a subjective experience of enjoyment and concentration that typically occurs during performance of tasks that are challenging but matched in difficulty to the person's skill level. Research in social psychology has identified nine elements in verbalizations of this state (Csikszentmihalyi 1990): (1) *challenge–skill balance* (the task is challenging but matched in difficulty to the skill of the person); (2) *action–awareness merging* (actions feel automatic, and few or no attentional resources are required for executing action sequences); (3) *clear goals*; (4) *unambiguous feedback*; (5) *high concentration*; (6) *sense of control*; (7) *loss of self-consciousness* (self-reflective thoughts and fear of social evaluation are absent); (8) *transformation of time* (time may seem to move either faster or slower than usual); and (9) *autotelic experience* (performance is accompanied by positive affect, which may be part of an intrinsic reward response—that is, performing the task becomes a goal in itself).

Flow proneness as a trait refers to the tendency of a person to experience flow states. It can be measured by questionnaires where participants indicate how frequently they have experiences with the various characteristics of the flow state summarized above (see, e.g., the Activity Experience Scale of Jackson and Eklund; Jackson and Eklund 2004). Two other traits that presumably are closely related to flow proneness will also be discussed here: *intrinsic enjoyment* and *boredom coping* (Hamilton, Haier, and Buchsbaum 1984). Intrinsic enjoyment refers to a tendency to perform activities because they are rewarding in themselves rather than because they are linked to external rewards. Boredom coping is a disposition to relate to and perform potentially boring tasks in such a way as to make them more intrinsically rewarding. A fourth proposed higher order trait, *autotelic personality,* appears related to all three of these constructs (Csikszentmihalyi 1990; Nakamura and Csikszentmihalyi 2009).

Flow, Flow Proneness, and Emotion

Before we can discuss the physiological underpinnings of flow and flow proneness, these concepts need to be related to relevant established knowledge on emotion, attention, and expertise.

Enjoyment is a central aspect of the flow experience. Furthermore, several other elements of flow are dependent on emotional state: Challenge appraisals and task engagement vary as a function of affect (Maier, Waldstein, and Synowski 2003); emotional stimuli can modulate attentional processes along the dimensions of valence and arousal (Brosch, Sander, Pourtois, and Scherer 2008; Jefferies, Smilek, Eich, and Enns 2008; see below); perceived personal control is related to greater self-reported coping ability prior to a task and lower self-reported stressfulness afterwards (Weinstein and Quigley 2006); positive emotions have been found to reduce self-conscious awareness of, for example, pain (Roy, Peretz, and Rainville 2008); and sense of time is altered such that highly arousing stimuli with positive valence are perceived as having shorter duration than negative, low-arousing stimuli (Droit-Volet and Meck 2007; Noulhiane, Mella, Samson, Ragot, and Pouthas 2007). Using the well-known two-dimensional affective space of valence and arousal (Lang 1995), a flow state would thus be associated with the upper right quadrant—that is, the flow experience includes an emotional state characterized by moderate to high levels of both dimensions.

Interestingly, the dimensions of valence and arousal are commonly found to also organize somatophysiological responses. Hence, by locating flow in the affective space, it is possible to yield a hypothesis about how psychophysiological measures of emotion correlate with state flow. Many studies have used electromyographical recordings of activity in facial muscles to differentiate between emotional states (see, e.g., Ravaja, Saari, Salminen, Laarni, and Kallinen 2006; Witvliet and Vrana 1995). Two commonly probed muscles in this context are the *corrugator supercilii* (CS), which is used during frowning, and the *zygomaticus major* (ZM), which is activated during smiling. CS activity increases during negative affect and decreases during positive affect. ZM mainly responds to decreases in negative affect (Larsen, Norris, and Cacioppo 2003). Activity in these muscles also depends on arousal: CS activity is highest during negatively valent low-arousal states, while ZM activity is maximal during positive, high-arousal (joyous) states (Witvliet and Vrana 1995). Arousal is also reflected in respiratory measures. Excited and aroused states are associated with rapid deep breathing accompanied by a high inspiratory flow rate (Gomez and Danuser 2004; Wientjes 1992). Cardiovascular measures, too, demonstrate emotion-specific autonomic activation: High-arousal emotions (such as joy) are reliably associated with decreased heart period (interval between beats) and increased systolic blood pressure (Ekman, Levenson, and Friesen 1983; Schwartz, Weinberger, and Singer 1981; Sinha, Lovallo, and Parsons 1992; Witvliet and Vrana 1995).

In addition, we can formulate hypotheses about the relation between flow proneness and other psychological traits that influence emotional processing. Specifically, one would predict a negative correlation between flow proneness and neuroticism. This higher order personality trait, which is highly consistent across various models of personality, including the currently dominating five-factor model of McCrae and Costa (1990), is characterized by a number of features that would tend to interfere with the affective component of flow states— in particular, a high reactivity to negative stimuli and a proneness to worry and negative affect (Gray and McNaughton 2000; McCrae and Costa 1990).

Flow, Flow Proneness, and Attention

Attention is a central component of human cognition and a prerequisite for being able to maintain goals and execute goal-oriented action (for a review, see Raz and Buhle 2006). As mentioned, an interesting aspect of the flow state is effortless attention: a subjective experience of heightened, unforced concentration and absorption in the ongoing performance. We suggest that this may occur as a result of an interaction between positive valence and attention. Positive valence can distract away from negative and even painful stimuli (Roy, Peretz, and Rainville 2008), that is, a task of great attentional load may be experienced as less effortful in a state of positive affect. This transient neglect could be explained by a propensity of brain systems to respond differently to a stimulus depending on whether attention is focused on sensory- or affect-related properties—for example, intensity or pleasantness (Grabenhorst and Rolls 2008).

In terms of psychophysiology, attention in the sense of mental effort is accompanied by higher activity in the CS (the "frown muscle"; Cohen, Davidson, Senulis, Saron, and Weisman 1992; Waterink and van Boxtel 1994), fast and shallow respiration (Backs and Seljos 1994; Veltman and Gaillard 1998; Wientjes 1992), and decreased heart period and increased systolic blood pressure, together with a decreased variability in these measures (Berntson, Cacioppo, and Quigley 1993; Middleton, Sharma, Agouzoul, Sahakian, and Robbins 1999; Porges and Byrne 1992; Richter, Friedrich, and Gendolla 2008; Veltman and Gaillard 1996, 1998), all of which points to an increased activation of the sympathetic nervous system. However, it should be noted that studies on individual differences in physiological response to, for example, working memory- and attention-demanding tasks show better performance to be associated with relatively greater—that is, less suppressed—heart rate variability related to vagal influence—that is, the parasympathetic component of the heart rate variability spectrum (Hansen, Johnsen, and Thayer 2003). The coupling between mental effort and shallow respiration is particularly interesting, since joyous states typically show deep respiration (see above). One could thus hypothesize that this measure distinguishes between states of effortful and effortless attention. In general, deep breathing is associated with decelerated heart rate and lowered blood pressure—something underscoring the importance of deep breathing to parasympathetic activation (see, for instance, von Schéele, von Schéele, Hansson, Winman, and Theorell 2005).

At a trait level, performance on tests of effortful, sustained attention show a substantial positive correlation with psychometric general intelligence (Schweizer and Moosbrugger 2004; Schweizer, Moosbrugger, and Goldhammer 2005). It is therefore of interest to examine whether flow proneness also shows a relation with intelligence and performance in sustained attention tasks. If this is the case, it would indicate that individual differences in the capacity for effortful and effortless attention share neural substrates. If not, it would provide further support for the hypothesis that effortless attention differs from effortful attention, perhaps because the absorption in a task during flow is more dependent on expertise—that is, a high level of skill in particular tasks that induce the flow experience—than on general cognitive ability (see below).

Expertise and Flow

Flow occurs during performance of tasks when the challenge of the task is on par with the skill level of the subject. An additional requirement appears to be that the task is at least moderately complex and challenging in absolute terms; too simple tasks are not flow promoting (Csikszentmihalyi 1990). What is most flow promoting for a given person will thus depend on the particular domains of expertise of that person. More generally, expertise, implemented as stored long-term representations in the brain, will guide planning and expectations (Ericsson and Lehmann 1996) and even influence sensory processing to attend to task-relevant cues (Summerfield, Lepsien, Gitelman, Mesulam, and Nobre 2006). Since top–down processes can modulate attentional focus and filtering processes, expertise can presumably also facilitate sustained attention and reduce distractibility in a domain-specific manner.

Another important aspect of expertise is automaticity (Ericsson, Charness, Feltovich, and Hoffman 2006). Nonautomatic behavioral routines can be gradually automated by extended training, practice, repetition, and overlearning. With greater automaticity, there is less need for higher order cognitive functions to micromanage sequential sensory and motor processes, which enables the automated processes to be carried out faster and more accurately while also being less vulnerable to attentional shifts. Focus can instead be allocated to speed and/or other more qualitative aspects of motor output, also making challenge per se qualitatively different at different levels of ability. Expertise also involves domain-specific changes in attentional function. An extraneous dual task can thus degrade performance in novices but not necessarily in experts. Furthermore, effortful attention to skill execution in experts can actually interfere with performance (Beilock, Bertenthal, McCoy, and Carr 2004; Beilock, Carr, MacMahon, and Starkes 2002; Gray 2004). These observations appear to support the idea that effortless attention during skilled performance in flow is different in nature from effortful attention to task.

Correlates of Flow

The existing literature thus allows one to make a number of predictions with regard to the underlying biology of flow and flow proneness. To summarize, physiological correlates of state flow should include decreased heart period, increased cardiac output, increased respiratory rate, increased respiratory depth, and differential activation of facial muscles involved in expression of emotion—that is, increased activity in the ZM and decreased activity in the CS. Flow proneness and related traits may show relations to numerous other traits influencing attentional and emotional processing, but we have focused here on two main traits: general intelligence, where we expect a positive correlation to the extent that effortless attention overlaps with mechanisms for effortful sustained attention, and neuroticism, where we predict a negative relation.

Very few studies have so far directly tested these predictions. To our knowledge, a recent study from our own group is the only one investigating physiological correlates of state flow while controlling for other variables that may influence physiology (de Manzano, Theorell, and Ullén 2008). In this study, the subjects ($n = 21$) were all professional concert pianists. Physiological measures included electromyograms of the CS and ZM muscles, heart rate, blood pressure, and thoracic respiration. During the experiment, the pianist played the same self-chosen musical piece (three to seven minutes' duration) repeatedly for five trials, thus keeping all sensorimotor processing and physical effort that could influence physiology essentially constant. Flow was measured after each trial using self-reports and then compared to physiological measures obtained during each trial. In line with the previously stated hypotheses, we found performance with higher flow to be associated with a decreased heart period, higher activity in ZM, and larger respiratory depth. No effect was found for CS activity or respiratory rate.

Correlates of Flow Proneness

A few studies have investigated psychological correlates of flow proneness and related traits. Hamilton and coworkers measured intrinsic enjoyment and boredom coping in around 160 subjects, who were divided into subgroups that were subject to different sets of additional measurements and tests (Hamilton, Haier, and Buchsbaum 1984). In one subsample of 18 students, the frequency of experiences relating to state flow was measured using the Experience Sampling Method (Csikszentmihalyi and Larson 1987). Intrinsic enjoyment was significantly related to several of these measures—that is, this trait seems substantially related to flow proneness. Trends for boredom coping did not reach significance in this relatively small subsample. Furthermore, intrinsic enjoyment was significantly related to higher *internal locus of control* (Rotter 1966), a trait which in turn is negatively correlated with neuroticism (Clarke 2004; Horner 1996). In a second subsample of 48 college students, a test of sustained attention (the continuous performance task) showed no relation to intrinsic enjoyment, and a modest positive relation to boredom coping ($r = .4$) was found.

We recently measured general intelligence (Raven's Standard Progressive Matrices Plus), personality (NEO Personality Inventory—Revised), and flow proneness in three domains of activity (professional, leisure time, and maintenance activities) in a sample of 76 university students (Madison, de Manzano, Forsman, and Ullén, in preparation). Interestingly, no relations between flow proneness and intelligence were found in this sample. In contrast, flow proneness during leisure showed a significant negative relation to neuroticism ($r = -.4$). A negative relation between neuroticism and flow proneness was also found in a sample ($n = 126$) of music students (Avsec and Smolej Fritz 2008). Clearly, further studies on relations between flow proneness and other traits in larger and demographically different (e.g., older) samples would be of interest.

The Physiology of Flow and Effortless Attention—Preliminary Observations

Conclusions regarding the biological basis of flow still have to be made with great caution, given that so few studies have been performed. However, the existing data support several of our hypotheses regarding differences in the underlying physiology of effortful and effortless attention. Our own study on pianists suggests that an increased activation of the sympathetic branch of the autonomic nervous system in combination with deep breathing is characteristic of the flow state. In other words, flow is a state of arousal, but it is accompanied not by the shallow respiration characteristic of mental effort but rather by the deep respiration typical of joyous states. This is compatible with our proposal that the flow state is the result of an interaction between positive affect and attention. Intuitively, too little or too much arousal in relation to task difficulty should decrease flow. One might speculate that this is reflected in the challenge–skill balance dimension and that arousal, thus, is related to optimal performance and flow as predicted by an inverted U-shaped relationship as in the much debated Yerkes–Dodson law (Hanoch and Vitouch 2004).

These findings also suggest that regulation of sympathetic and parasympathetic activity levels may be of importance for state flow. In general, the parasympathetic system can be regarded as a system that counterregulates a general stress–arousal reaction. Indirect evidence for concomitant activation of the sympathetic and parasympathetic systems in music performing professionals comes from a study of a singing lesson in which professional singers were compared to amateurs (Grape, Sandgren, Hansson, Ericson, and Theorell 2003). During singing, the increase in heart rate was very similar in the two groups. However, in the professionals heart rate variability increased markedly, whereas no such increase was observed in the amateurs. This was particularly pronounced for low-frequency power, which has been assumed to reflect a mixture of parasympathetic and sympathetic activity (Porges and Byrne 1992), but it was noticeable also in high-frequency power, which reflects parasympathetic activity. Preliminary data on piano performance from our group are also in line with this. In three of the pianists participating in the above-mentioned study (de Manzano et al. 2008), additional physiological measurements—continuous recordings of electrocardiogram and pCO_2 in exhaled air—were made during performance of both the self-selected, well-learned piece and a difficult, unknown piece (the fourth movement of György Kurtág's *Splinters*) that had to be played *a prima vista*. During playing of the unknown piece, as compared to the self-selected piece, all three pianists showed an increase of high-frequency power in heart rate variability, and also a longer heart period, a higher respiratory rate, and a lower pCO_2. These findings suggest that the professional pianists were able to immediately activate the parasympathetic system in the difficult *prima vista* situation. It appears possible, therefore, that the ability of experts to regulate the level of activity in both sympathetic and parasympathetic branches of the autonomous nervous system during performance is of importance for state flow, but further research is obviously needed to test this idea.

Differences in physiology suggest differences in neurophysiology. Further work is needed to elucidate the neural correlates of the flow experience, but an interesting speculation is that flow may have commonalities with states experienced during deep meditation and that the anterior cingulate cortex may play important roles for the coordination of autonomic responses and cognitive control in such states (Posner, Rothbart, Rueda, and Tang, chapter 16, this volume; Siegel 2007).

That the affective component of flow is essential for effortless attention is also supported by the fact that flow proneness is related to emotional stability (i.e., low neuroticism) and internal locus of control (Avsec and Smolej Fritz 2008; Hamilton, Haier, and Buchsbaum 1984; Madison, de Manzano, Forsman, and Ullén, in preparation). The lack of a positive correlation between flow proneness and intelligence in our sample of young adults (Madison et al.) as well as between flow proneness and sustained attention (Hamilton et al.) is a further indication that there are essential differences in the mechanisms underlying effortful and effortless attention. One explanation for this may be that the absorption in an activity during flow is less dependent on general cognitive ability than on high skills in particular domains—that is, expertise—which allows the person to perform specific flow-promoting tasks at a high level. This would be in line with sociological studies showing that flow experiences are common among people at different educational levels but that the flow-promoting activities differ depending on the expertise of the subjects (Csikszentmihalyi 1990). The importance of intelligence for expertise remains a question of debate, but it appears uncontroversial that for most domains practice is a better predictor of expert performance than cognitive ability (Ericsson, Charness, Feltovich, and Hoffman 2006). To get a more conclusive picture of the relation between flow proneness, intelligence, and expertise, however, studies on larger cohorts with a wide range of cognitive ability as well as expertise in different domains would be important.

The Psychophysiology of Flow and Health

There are several published studies which show that there is a positive relationship between health and a high prevalence of positive emotions in daily life. If we assume that flow would increase the prevalence of positive emotions, this would be of relevance. For instance, in one study (Theorell, Ahlberg-Hulten, Jodko, Sigala, and de la Torre 1993) female health care staff were asked to record emotions every hour during an ordinary working day. Blood pressure was recorded on all these occasions. The findings indicated a strong relationship between a high prevalence of joyful feelings and a low blood pressure level during working hours as well as at rest and during leisure hours. In a large prospective cohort study, Kubzansky, Sparrow, Vokonas, and Kawachi (2001) showed that optimism in general was associated with a markedly reduced incidence of coronary heart disease (after adjustment for other risk factors). Of more direct relevance is the observation by Bygren, Konlaan, and Johansson (1996) based upon a cohort study of randomly selected Swedes. They were asked whether they participated at least once a week in cultural activities (which should increase the number of flow experiences) or not. Those who did so had a better survival during follow-up than other participants in the study. This association remained significant after adjustment for education, income, health at start, and life habits (such as smoking) that are of relevance to survival and which may also be related to participation in cultural activities. In a small randomized study by our own group (Grape, Sandgren, Hansson, Ericson, and Theorell 2003), adult beginners in choir singing showed increased saliva testosterone concentration and reported increased vitalization during the initial months. The control group showed no such increase. Moderate increase in saliva testosterone is an indicator of improved cell regeneration and therefore of relevance to this question. Furthermore, as we speculated above, parasympathetic mechanisms may be of importance for flow. During recent years, it has been pointed out that activation of the parasympathetic system is helpful in the recovery phase after an arousal reaction and that this stops inflammatory reactions that stimulate, for instance, the atherosclerotic process (Gidron et al. 2007). The ability to activate the parasympathetic system could thus be of importance for flow as well as long-term health and longevity. In summary, there is indirect but no direct evidence that a high prevalence of flow experiences could benefit health.

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