A Systematic Review on Flow States from a Neurocognitive Perspective

Yihui Zhong[1,*]

[1] Shanghai American School, Shanghai, 201107,China

*Corresponding author. Email: Angelazhong0712@gmail.com

Abstract. The term "flow", also referred to as the optimal experience, describes a state of full engagement and absolute concentration that brings about a sense of effortlessness and pleasure, and, as a result, leads to peak performance. There are eight major components of flow: (i) the balance between the challenges faced and the available skills level; (ii) the ability to concentrate on the present task; (iii) clear goals; (iv) immediate feedback; (v) a sense of deep but effortless involvement; (vi) sense of control; (vii) decreased self-consciousness during flow, which becomes stronger afterward; and (viii) altered perception of time. The present study offers a comprehensive analysis of the flow theory, examining both the theoretical framework and conceptualization of flow, as well as the neurocognitive mechanisms that are involved in flow. In particular, the research focuses on providing a thorough assessment of the neural correlates of flow, systems and networks involved in flow, and the neurocognitive mechanisms underlying the induction and maintenance of flow. The present study concluded that in future, more in-depth investigation of flow from a neurocognitive perspective is needed before conclusive explanations for the neural mechanisms underlying flow can be made.

Keywords: Flow State; Optimal Experience; Neuroscience; Mechanisms of Flow; Positive Psychology

1 Introduction

The term "flow", also known as the optimal experience, refers to a state of full engagement, absolute concentration, a sense of effortlessness and pleasure, and peak performance. Since Csikszentmihalyi (1975) initially coined the term "flow", researchers in positive psychology started exploring flow state and its outcomes. Sports, arts, music, and other psychology studies have focused on flow because of its link to peak performance[1]. In addition, research in positive psychology also reveals that flow is a positive psychological experience that benefits one's well-being and happiness[2].

The development of neuroscientific technology has provided a new perspective to understand flow. The operationalization and the precise neural mechanisms of flow

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remain unclear till now. This requires various theories and hypotheses to be made and a multitude of findings to be reported.

The present study's goal is to provide a comprehensive overview of the neural functioning of flow and the brain structures that are potentially involved during flow. A literature search was conducted online via the following platforms: Google Scholar, the Psychology and Behavioural Science Collection, PsycArticles, PsycInfo, and Science Direct. The following keywords were used for the search: flow state, flow experience, flow theory, neuroscience, and neurobiology. There are no specific inclusion and exclusion criteria. Articles from inception to October 2022 were included.

2 Flow

2.1 Definition of Flow

The phenomenon of flow was first conceptualized by Csikszentmihalyi in 1975 in his famous book Beyond Boredom and Anxiety, in which flow was defined as a "holistic sensation that people feel when [acting] with total involvement". Csikszentmihalyi (1990) further explained the flow theory and suggested the eight major components of flow[3]: (i) the balance between the challenges faced and the available skills level; (ii) the ability to concentrate on the present task; (iii) clear goals; (iv) immediate feedback; (v) a sense of deep but effortless involvement; (vi) sense of control; (vii) decreased self-consciousness during flow, which becomes stronger afterward; and (viii) altered perception of time. Later, Csikszentmihalyi (1993) concluded the nine characteristics of flow, in which (ix) the experience is autotelic is included[4].

The flow theory was later specified into three stages: the antecedents of flow, the flow state, and the outcomes of flow[5]. The outcomes of flow include an increase in happiness, subjective well-being, and life satisfaction[2].

Flow is also found to be associated with improved performance in multiple domains such as sports, work, and gaming[6]. It is also suggested that focusing on the goal instead of oneself and the absence of worry and anxiety may also be beneficial to performances[7][8][9].

Generally speaking, ways of measuring flow have greatly evolved over time. Therefore, the next section will provide a critical review of past and present tools to measure flow as well as their advantages and disadvantages.

2.2 Traditional Ways of Measuring Flow

Self-report Questionnaires. Initially, Csikszentmihalyi studied flow by conducting interviews with people from a wide range of occupations. The key characteristics of flow were then selected and compiled into the first method to measure flow, the Flow Questionnaire (FQ).

Multiple flow questionnaires have been developed to obtain a better understanding of flow, which examines flow from different aspects. For instance, the FPQ measures presence and flow state of users of technological devices[10]. The FSS is intended to measure flow experiences in a sports context[11]. Other questionnaires include the 12-item Flow Scale, the Flow Short Scale, Online Flow Questionnaire (OFQ), and the Situation-Specific Flow Questionnaire [2][12][13]. These questionnaires are developed to measure flow in particular professional endeavors or environment.

The strength of questionnaires lies in its ability to collect a large amount of quantitative data, allowing conclusions to be drawn based on statistical analyses and quantitative models to be established. However, questionnaires limit the ability to obtain more in-depth information about the subjects' thoughts, feelings, and narratives of their experiences.

Interviews. Early flow research relied on interviews, especially semi-structured[14]. Sugiyama and Inomata (2005) examined top athletes' psychological factors and flow antecedents using semi-structured interviews[15].

Although interviews are useful for gathering qualitative data, they don't reveal much about the quantitative components of flow. Interviewing people shortly after or during their flow experiences and completing numerous interviews over time helps mitigate this issue[16].

Experience Sampling Method (ESM). Csikszentmihalyi used the Experience Sampling Method to research daily flow experiences[17]. ESM uses a representative sample of daily living to "describe changes in self-reports of mental processes." The Experience Sampling Form (ESF) includes open-ended questions concerning location, time, activity, thought content, and a set of scales that measure emotional experience, cognitive efficiency, and motivation, depending on the research goal[18].

The greatest advantage of ESM is its timeliness in collecting people's experiences and current mental states. ESM significantly reduces the potential ambiguities and reconstructions during memory recollections due to the unreliable nature of human memories. ESM data is subjective and unreliable because participants self-report. Electrical signals repeated throughout the day may bother some participants and prompt them to drop out, biasing the sample.

In summary, the majority of research that utilized the above methods is still limited to examining the behavioral aspects of flow, while little is known about the accurate conceptualizations of flow and the mechanisms that cause flow states.

2.3 Theoretical Frameworks

Original Flow Model. Csikszentmihalyi (1975) proposed the very first flow model utilizing FQ (see Figure 1), contending that flow occurs when challenges and skill level are in balance. The model divides the Cartesian plane into three sections, each of which represents a different mental state: flow, boredom, and worry. During boredom, one's talents are enough to overcome the perceived obstacle, but anxiety emerges when the problems exceed one's capacity.

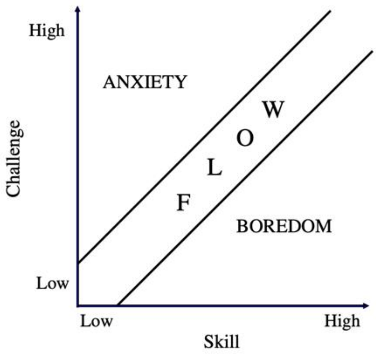

Fig. 1. The original flow model proposed by Csikszentmihalyi (1975)

The Quadrant Model. Due to conflicting theoretical findings, this original paradigm was recast in 1988. The new quadrant model (see Figure 2) proposes that flow only occurs when challenges and skills are both high[19]. The flow theory was also reformulated by adding another requirement to the original antecedent "balance between challenges and skills", with the new condition possessing two key aspects: (i) challenges must be balanced with skills (ii) both challenges and skills have to be high[20]. The advantages of the model are its simplicity as a classification system and its ability to perform simple tests. However, It is also criticized for being overly simplistic since practical definitions for defining the difference between "high challenge" and "low challenge".

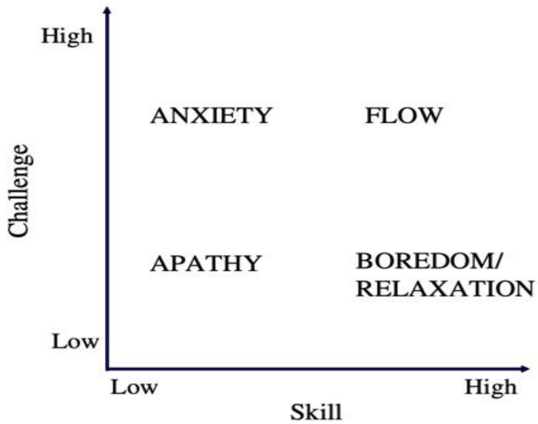

Fig. 2. Reformulated flow model proposed by Csikszentmihalyi and Engeser, S., Rheinberg[19][21]

The Experience Fluctuation Model. The Experience Fluctuation Model (Figure 3) proposed by Massimini and Carli (1987) reflects an attempt to establish a more accurate classification system of flow. The model divides the Cartesian plan into eight channels represented by 45-arc sectors, standardizing both axes with the subjective mean at 0. Each channel represents a mental state. When the perceived challenge is greater than skills, one is more likely to experience anxiety or worry depending on the level of challenges[22]. However, when one's perceived skill is more than enough to cover the challenge, the experience of relaxation or boredom is a likely result. Flow only occurs when challenges match skills and both are high[23]. Based on the assumption that there is a relationship between quality of experience and perceived skills and challenges, this model empirically assesses experience fluctuation.

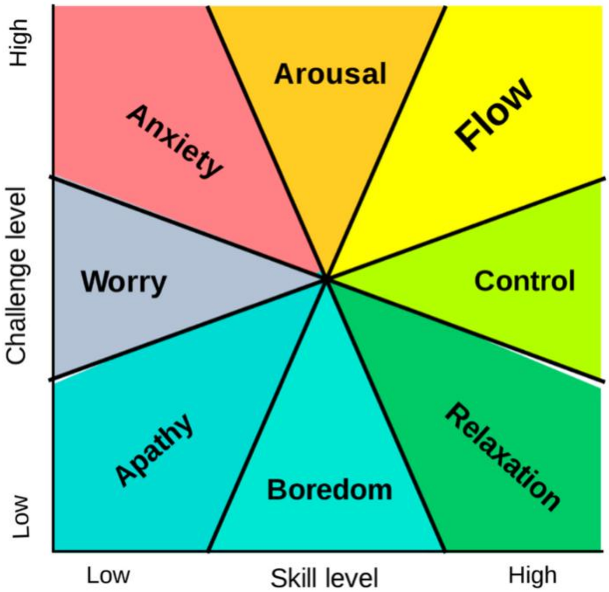

Fig. 3. Reformulated flow model proposed by Massimini and colleagues[24]

2.4 Summary

Whether flow is continuous or discontinuous is debated. An accurate operational definition and factual and subjective flow experiences are needed to distinguish flow from other mental states. Thus, neuroscientific study of flow experience may improve flow research and operationalization.

3 Neuroscience

3.1 Definition of Neuroscience

Neuroscience refers to the study of the nervous system and its functions. Neuroscience can offer vital insights into the underlying mechanisms of the patterns in behavior observed by psychologists. Research in neuroscience often substantiates psychological theories with empirical evidence or reveals new findings that indicates potential directions of future research in psychology.

3.2 Tools Used in Neuroscience Research

Modern neuroscience tools like electroencephalography (EEG), functional magnetic resonance imaging (fMRI), and positron emission tomography (PET) can visualize and quantify live brain activity during various mental processes[25]. This section of the paper seeks to provide an overview of common tools that are often used in neuroscientific research of flow experience.

Eeg. Electroencephalography (EEG) is a method that records the aggregate sum of the brain's spontaneous electricity of postsynaptic signals of neurons, both inhibitory and excitatory[26]. Signals detected and recorded by EEG reflects the synchronous activity of thousands of neurons and even more; the summation of these activities is what is commonly known as the brain activity[27]. EEG also provides critical clues to mental or neurological disorders such as epilepsy, sleep disorders, and stroke. EEG signals, usually described in terms of frequency bands, also reflect different mental states.

The strength of EEG is that it can observe in-vivo brain activity at millisecond time scales by detecting changes in a short amount of time[27]. EEG is also one of the few advanced tools of research that directly measure the electrical activities of the brain instead of using indirect evidence like blood flow.

MRI and fMRI. Magnetic Resonance Imaging (MRI) employs high magnetic fields and radio waves to create images of body organs and issues[28]. MRI was developed after the phenomenon of Nuclear magnetic resonance, the production of electromagnetic signals in the nucleus that matches the frequency of the magnetic field as a result of being disturbed by the magnetic field[29]. In a high magnetic field created by powerful magnets, tissues with free hydrogen nuclei (protons) generate fluctuating radio signals that are used to create an image of the structure's architecture[30]. MRI can provide high-quality images, showing exceptional anatomical details and clear contrasts between the gray and white matter[31].

fMRI started the "imaging revolution" in 1990. fMRI has played an important role in understanding the physiological basis of cognition. fMRI takes advantage of the fact that neural activity causes the brain to bring in more oxygen, which binds to hemoglobin molecules in the blood. The fMRI detectors measure the ratio of oxygenated to deoxygenated hemoglobin; this value is referred to as the blood oxygen level–dependent, or BOLD, effect[32].

fMRI has led to revolutionary changes in cognitive neuroscience. fMRI uses no radioactive tracers, so it does not incur the additional costs, hassles, and hazards associated with handling these materials. Because high-quality anatomical images are taken using standard MRI while the individual is in the scanner, fMRI has better spatial resolution than PET.

Tms. Transcranial magnetic stimulation (TMS) allows researchers to probe causality in brain in health people, which was extremely hard decades ago[33]. TMS is a non-invasive method that allows scientists to causally manipulate by disrupting brain activity with electrical currents, which can help establish a causal relationship between a particular brain region and a given mental process by analyzing the impact of intentionally "silencing" this region. This technology is appealing since it is safe, noninvasive, and only briefly alters brain activity. Thus, performance can be compared between stimulated and non-stimulated conditions in the same individual.

4 The Neuroscience of Flow

Neuroscience researchers are attempting to identify and measure brain activity that are common to numerous flow-inducing activities and can be applied to a broader population[34]. Neuroscientists employ brain imaging to study flow state-related neuronal systems in labs[35][36].

4.1 Neural Correlates of Flow

Prefrontal Cortex. Yoshida et al. (2014) used fNIRS to measure prefrontal cortex flow neural correlates. The flow condition activated the right and left ventrolateral prefrontal cortex, right and left frontal pole regions, and left VLPFC. The flow state scale showed that boredom reduced Oxy-Hb concentration[37]. This shows that the aforementioned brain areas were only activated in flow situations.

Harmat et al. (2015) observed no link between flow and prefrontal activation[38]. Limb and Braun (2008) induced flow states in six full-time jazz players by improvising[39]. Flow conditions were related with extensive deactivation of superior dorsolateral PFC and dorsal medial PFC. Researchers also found medial PFC focal activation. Improvised music is musicians' self-expression, so MPFC's selective activation during flow supports the idea that MPFC is engaged in person perception, theory of mind/mentalizing, and self-motivated action[39][40].

Frontal Gyri. Flow states may also involve the IFG. Ulrich et al. (2014) discovered that mental arithmetic flow increased IFG activity in MRIs[41]. Ulrich and colleagues (2016) used the same mental arithmetic tasks but fMRI to explore frontal gyri as neural correlates of flow[42]. IFG were seen during flow in the second research.

Yoshida et al. (2014) similarly found increased activity in the inferior frontal gyrus during flow-inducing activities using fNIRS[37]. Further, Klasen et al. (2012) demonstrated that there is an increased activity in medial frontal gyrus[43].

Miscellaneous Others. Neuroscience studies describe conflicting brain correlates of flow states. Limb and Braun (2008) found higher ACC activity during spontaneous music improvisation in professional musicians using fMRI[39]. Other researchers contradicted Limb and Braun's conclusions[41][42][43]. This suggests that, though ACC is known to be involved in cognitive processes including but not limited to motivation, decision making, behavior monitoring, and learning, the way ACC interacts with the state of flow remains poorly understood[44].

Flow activated multiple brain areas. Klasen et al. (2012) found greater midbrain reward activation during flow. Cerebellum, visual system, precuneus, and premotor region activity increased as players focused[43]. Limb and Braun (2008) added that flow activates the ventral and dorsal lateral premotor areas, supplementary motor area, and primary motor cortex[39]. Flow-producing spontaneous music improvisation specifically stimulated the cingulate motor region, right lateral cerebellar hemisphere, and vermis. Flow was also thought to deactivate the medial prefrontal and posterior cingulate cortex, the amygdala, the bilateral intraparietal sulcus, and the orbitofrontal cortex [42][43]. Flow decreased activation in the hippocampus, parahippocampal gyri, hypothalamus, and entorhinal cortex.

In summary, the extant literature has found distinct patterns of brain activity emerged during flow states, thus sufficiently confirming the existence of flow as a unique mental state. However, the discrepancy in findings reveals the complexity of flow and difficulty of quantifying the subjective experience of flow, highlighting the need for further research.

4.2 Systems and Networks Involved in Flow

Systems involved in Flow. In search of the neural correlates of flow state, several brain systems have been pointed out as potential neural underpins of this experience. One of the most highlighted neural system is dopaminergic reward system. Findings showed that areas related to the this system are more active during flow[41][42]. Activity of the reward system tends to coincide with feelings of optimism and hope, positive mood, and feeling energized or motivated[45]. In addition, dopamine can reduce feelings of fatigue or discomfort[46]. These properties of the dopaminergic reward system, thus, fit with important dimensions of flow, such as intrinsic motivation, and a relentless dedication to a task.

In comparison to dopaminergic systems in flow, less attention has been given to the locus coeruleus-norepinephrine (LC-NE) system. The LC-NE system regulates decisions regarding task engagement vs. disengagement. In a recent review, Van der Linden et al. (2021) emphasized the theoretical and empirical overlap between the LC-NE system and flow[47]. To increase task-related attention, skill and task challenge must match. Flow is related to arousal in an inverted U-shape. Similarly, in theories on the LC-NE system, task engagement is highest with intermediate levels of arousal. In conclusion, understanding how the LC-NE system creates the flow sensation can help us understand flow and reconcile scientific results on the topic.

Networks involved in Flow. Experimental investigations on flow state and neural dynamics suggest that some brain networks are crucial to flow experience. The default mode network, which includes the anterolateral middle temporal cortex, posteromedial cortex, angular gyrus, inferior frontal gyrus, and medial prefrontal cortex, is involved in resting, mind-wandering, and higher-order cognitive functions (e.g., decisions based on internal rules)[48].

Task engagement or absorption is a sign of flow. Task-irrelevant stimuli or thoughts are inhibited. Flow-related concentration may involve the brain's central executive network (CEN)[47]. The CEN is a collection of brain areas that support higher-order cognitive functions such as working memory, attention, and inhibition[49].

A third network-the salience network-links the task-positive and the default mode network[50]. The salience network serves to detect important stimuli in the internal or external environment and direct attention toward those stimuli as a function of their sensory salience and motivational priority. The salience network is proposed to undergird the initiation of the flow experience, serving as the inflection point between non-flow and flow experiences[51].

4.3 Neurocognitive Models of Flow

Transient Hypofrontality Hypothesis and Implicit Vs. Explicit System. Dietrich (2004) proposed the transient hypofrontality hypothesis (THH) for flow as a state of transient downregulation of the prefrontal cortices, defining flow processes in the form of explicit and implicit information-processing systems[52]. The THH describes flow as requiring the full support of the implicit and automatic systems to execute a task at optimal output, while inhibiting most prefrontal cognitive functions. The THH places major emphasis on two principal functional changes for the induction of flow states. First, the inhibitory process of the prefrontal cortices frees up a computational bottleneck of the explicit systems. Second, manipulating implicit systems in the basal ganglia automates action.

Synchronization theory of flow. The THH has been contrasted with the synchronization theory of flow (STF) [53], which may help explain holistic, higher-order experiences that cannot be explained by isolated traits. STF claims neuronal activity synchronization allows "whole-brain" integration across several concurrent activities. A global efficiency score shows that large-scale neural synchronization, an energetically cheap state of consciousness, makes flow enjoyable rather than taxing[54]. Thus, during flow, particular attentional and reward networks should synchronize hebbianly[53].

Cerebellar internal models. The THH and STF appear to focus on mental economy, implicit processing, and synchronized activation of the striatal reward system linked with intrinsic motivation, however conflicting data supports and refutes hypofrontality and the importance of synchronous networks for flow. A more comprehensive neurocognitive model of flow states may address these parallels and distinctions while explaining other fundamental brain systems functioning.

It has been suggested that the brain makes use of an internal model which provides a sensorimotor representation of oneself with the world around. Internal models overcome the diminished speeds of neural conduction by providing predicted information about future properties of elements within the task to allow for faster interpretations and reactions within the task. The cerebellum forms an internal model during skill acquisition using generalized error prediction and supervisory learning systems that adjusts as the behavior is executed by merging reactive reflexes with anticipatory actions[54].

5 Conclusion

The current study provides a comprehensive review of the flow theory, focusing on its conceptualization, theoretical underpinnings, and associated neurocognitive mechanisms. The study also offers a thorough analysis of the flow-related systems and networks, brain correlates of flow, and neurocognitive mechanisms. Before definitive answers for the cerebral mechanisms underlying flow can be provided, more research on flow from a neurocognitive perspective is required.

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