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Original Paper

Neural Mechanisms and Benefits of Flow: A Meta Analysis

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Abstract

Known as "in the groove" by musicians and "in the zone" for athletes, flow is a sensation of total concentration on a single task. Since the introduction of flow theory by Mihaly Csikszentmihalyi in the 1970s, researchers have continued to explore the brain science and performance benefits of such state. The three hypotheses at the forefront of flow theory include brain waves, transient hypofrontality hypothesis, and synchronization theory of flow. Beyond detailing research that supports the three hypotheses, this meta analysis works to communicate the benefits of flow and also techniques to achieve the state. Flow state can be broken down into nine main characteristics, and working to improve each individual feature can contribute to optimizing the overall flow experience. The real world implications of flow state are immeasurable, allowing humans to be more efficient learners and better creative thinkers. Most importantly, flow is not an esoteric phenomenon exclusive to people at the top of their profession. Everyone can achieve flow state, which makes the benefits tangible and realistic for all. Flow theory continues to be a heavily researched subject in psychology, and a greater public interest in the topic can further expand the field of flow science.

Keywords

flow, in the groove, in the zone, neural mechanisms, benefits, analysis

Introduction

More than 2 billion people watch the Olympics at home. Athletes have all pressure on them, yet it is in stages like this that they excel the most and break world records. Referred to as "in the groove" by musicians, "in the zone" for athletes, and "runner's high" for others, the sensation of total concentration on a single task is the sensation of flow.

In the 1970s, flow theory was introduced by researcher Mihaly Csikszentmihalyi, based on his research observing people doing activities for pleasure, even without a monetary incentive or fame. He studied chess grandmaster, professional athletes, writers, artists, surgeons etc., and, surprisingly, these individuals found most pleasure out of their respective professions when they could enter an intense state of concentration and isolation. Flow was correlated with a positive experience and it is connected to peak performance (Csikszentmihalyi, 1970).

Flow can be characterized with nine key features: challenge and skills balance, action and awareness merging, clear goals, unambiguous feedback, concentration on the task, sense of control, loss of self-consciousness, distorted sense of time, autotelic experience. Flow occurs when there is a perfect balance between challenge and skill: too easy and the task becomes monotonous, too hard and the task becomes exhausting. Additionally, given a clear purpose, awareness, and feedback, one can fall into a state of concentration on a single task. The result of flow is a loss in the perception of time. Flow is also characterized as an autotelic experience, which is a sense of gratification that directly comes from the activity and not fueled by an end goal. The autotelic nature of flow makes it desirable because the activity of entering flow becomes its own reward (Csikszentmihalyi, 1990).

Experienced by many, understood by few, flow continues to be a topic of research and experimentation. Flow is an interdisciplinary field of study. Sports psychologists and neurobiologists alike are working to understand the phenomenon. Flow is not only a mental experience, but also a physical one. The physiological body is altered during heightened states of flow. This meta analysis works to understand the physiological indicators, benefits in performance, and ways to unlock a state of flow.

Neural Mechanisms of Flow: Brain Waves

The brain is a neural network, run on the electrical synapses of billions of neurons. In the central nervous system, the flow of ionic currents through the synaptic cleft allow neurons to communicate through electrochemical signals. The synchronization and unique firing patterns of neurons create distinct neuronal oscillations called brain waves (Buskila et al., 2019). There are 4 distinct types of brain waves that each map out a different state of consciousness: alpha, beta, delta, and theta.

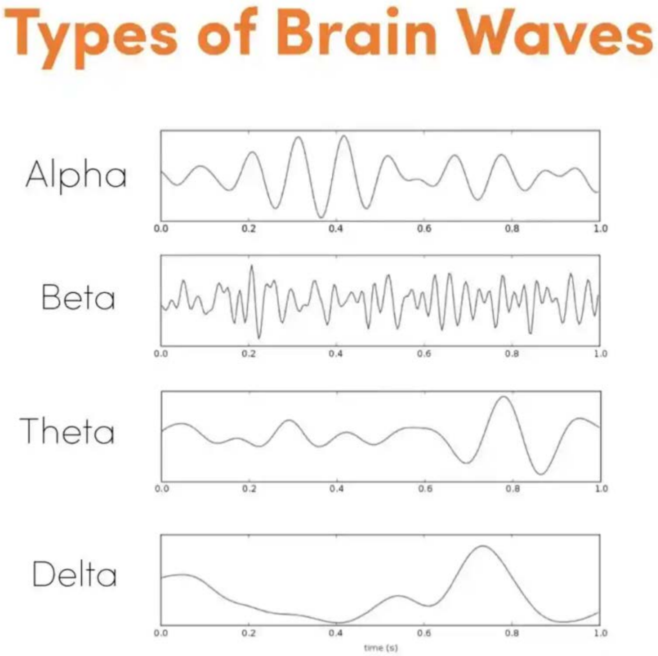

Image 1. A Model of the Four Types of Brain Waves and their Respective Frequency (Hz)

Alpha waves oscillate at a frequency of 8-13 Hz. A Hertz (Hz) is the number of cycles the wave travels in one second. These waves are most prevalent when an individual is awake, relaxed, and resting, and most abundant in the occipital lobe when the eyes are closed, blocking visual input to the occipital area. Alpha waves also have high amplitudes of 20-200 µV, and can be easily distinguished from the other waves on an Electroencephalogram (EEG). Alpha waves disappear when the individual falls asleep (Webster et al., 2010).

Beta waves oscillate at a frequency of 14-30 Hz. The high frequency, low amplitude waves can be seen in states of consciousness, focus, and alertness. These tasks occur in the parietal lobe and prefrontal cortex of the brain, which is also why beta waves are most prominent in these same regions (Barone et al., 2021).

Theta waves oscillate at a frequency of 4-7 Hz. Observed in states of daydreaming and borderlands between sleep and consciousness, these waves are found in the parietal and temporal lobes of the brain. Theta waves are more abundant in early life and gradually decrease as one ages. They are responsible for the processing and storage of memory (Scottsdale Neurofeedback Institute, 2022).

Delta waves oscillate at a frequency of 0.5-3 Hz, low frequency waves and high amplitude. Most abundant during deep sleep, these waves are located within the cortex of the brain. They are responsible for recovery and transfer learned material into long-term memory (Webster et al., 2010).

Mapping brain waves on an EEG, researchers found that, in states of flow, the brain shifted from beta waves to alpha and theta waves. A shift from a hyper-active mind to a subconscious and relaxed one

(Katahira et al., 2018). Furthermore, in a study conducted by neuroscientist Charles Limb et al. (2008) to examine the brains of jazz musicians in states of flow, Limb utilized functional MRI to research the musicians during improvisation. Jazz performers use a composition of chord structures and melodies for an improvised solo, and no two jazz improvisations are identical. The researchers hypothesized that the creative nature of improvisation would create discrete changes in prefrontal activity. Limb found that the dorsolateral prefrontal cortex, responsible for task switching and self-monitoring, was deactivated.

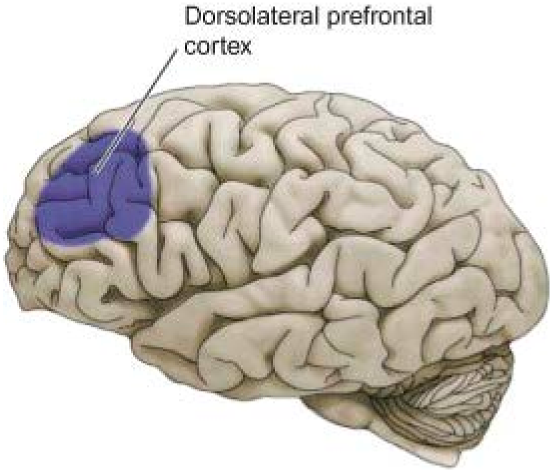

Image 2. Region of the Brain Deactivated during States of Flow

In the study, researchers found that consciousness, beta waves, disrupted the state of flow and the induced subconscious allowed the musicians to act without fear or hesitation.

Neural Mechanisms of Flow: Transient Hypofrontality Hypothesis (THH)

Another way researchers scientifically define flow is through the Transient Hypofrontality Hypothesis (THH). The phrase transient hypofrontality literally means “less activity of the frontal cortex”. Transient hypofrontality hypothesis suggest that during exercise increased neural activity required to operate gross motor control, sensory input, and autonomic regulation result in a decrease of neural activity in the prefrontal cortex (Dietrich, 2006). Essentially, muscle memory and intuition take the place of higher level decision making. Before the term was even coined, researchers studied the areas of high Local Cerebral Glucose Utilization (LCGU) in mice during exercise. LCGU is an index of the functional activity of neurons. In the study, rats ran on a treadmill for 30 minutes with a 85% maximum O_2 uptake. Results found substantial increases in LCGU in all brain structures except in the prefrontal cortex (Vissing et al., 1996). This hypothesis also supports the previous biological definition of flow, as a decrease in activity of the prefrontal cortex is similar to the decrease in beta waves during flow. Furthermore, the functions alpha and theta waves also align with the increase in gross motor control, sensory input, and autonomic regulation that occurs during exercise. Dietrich and Stoll (2010) posit that sports are good at inducing flow for two main reasons. First, physical motions are extremely complex and precise in sports, which requires a considerable amount of mental resources. Second, as the physical movements in sports become under control by the basal ganglia and autonomic, especially prevalent in professional athletes, less activity in the frontal regions for conscious decision making is required. The physical nature of sports and the transient hypofrontality theory supports the explanation for why so many athletes experience flow state.

Neural Mechanisms of Flow: The Synchronization Theory of Flow (STF)

The Synchronization Theory of Flow (STF), proposed by Weber and Tamborini, contradicts the previous theory of transient hypofrontality. Weber and Tamborini (2009) posit that flow results from the cognitive synchronization of particular attention and reward pathways that promote “holistic, higher-order experiences” that resemble flow states. THH is disputed by STF because many flow state activities like hypnosis and meditation show strong neural activity in the frontal regions, despite being in an altered state of consciousness and flow state (Gold et al., 2020). In a study by Klasen et al. (2011), researchers simplified a video game into five operational elements of flow, balance between ability and challenge, concentration and focus, direct feedback of action results, clear goals, and control over the situation, and used a fMRI to map the brain activity of attention and reward structures that support STF. Research Mihaly Csikszentmihalyi proposed nine elements to describe flow, and the researchers focused on five of these elements (Csikszentmihalyi, 1970). The thirteen male participants were given MR compatible headphones, video screens, and response devices to play a first person shooting game during the fMRI brain scan.

The researchers defined balance between ability and challenge by moments of success (virtual killing) and failure (virtual death) respectively. Balance was assumed in moments of success and absent in moments of failure. In the end, researchers observed 1064 success events and 338 failure events. The success events lead to stronger activation of midbrain structures, nucleus accumbens, putamen, cerebellum, thalamus, parietal and occipital areas, and premotor cortex. On the other hand, the failure events led to increased cuneus activity.

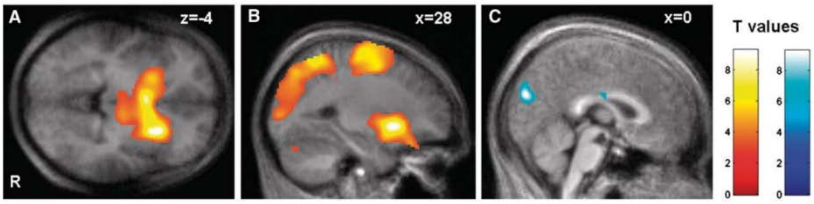

Figure 1. Balance between Ability and Challenge

Success led to activation in midbrain structures, nucleus accumbens, putamen, cerebellum, thalamus, parietal and occipital areas, and premotor cortex (A and B). Failure events led to increased cuneus activity (C).

Concentration and focus was broken down into 3 phases of the game. Participants were considered to be in low focus during waiting time in between rounds, medium focus when opponents were visible, and high focus during active combat. Increases in a player's focus increased the activation in the cerebellum, visual systems, precuneus and premotor areas, as well as a decrease of activation in bilateral intraparietal sulcus and orbitofrontal cortex.

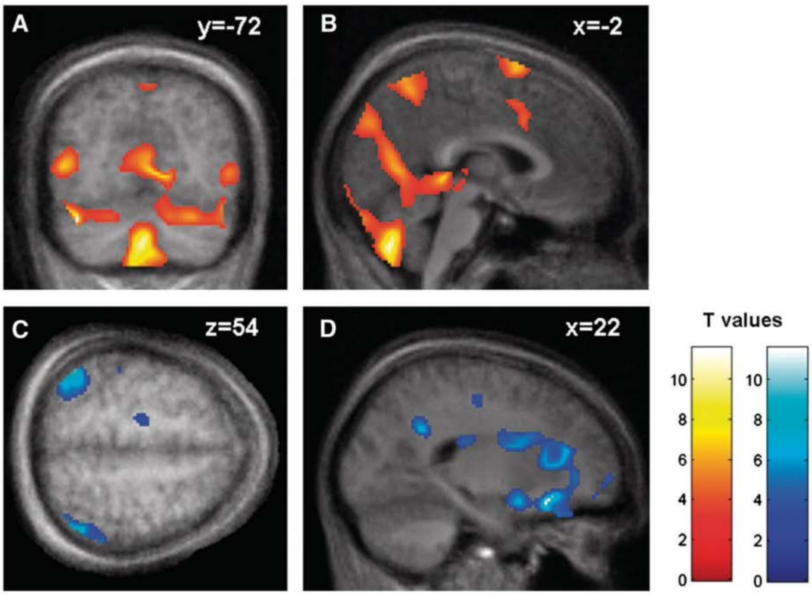

Figure 2. Concentration and Focus

Higher focus led to the activation in the cerebellum, visual systems, precuneus and premotor areas (A and B), as well as deactivation in bilateral intraparietal sulcus and orbitofrontal cortex (C and D).

Direct feedback of action results is an indicator of the player's abilities. Within success events, high feedback was coded if the player interacted with the body after a virtual kill, and low feedback was coded when the former was not observed. The analysis of the fMRI data revealed no significant effects.

Clear goals strengthen the immersiveness of the activity. If players stayed in game phases without visible or audible enemy contact for longer than 10 seconds, they would be considered to lack a clear goal. Phases with clear goals led to the activation of bilateral IPS, fusiform face area, and decreased activation of the dorsal anterior cingulate cortex and precuneus.

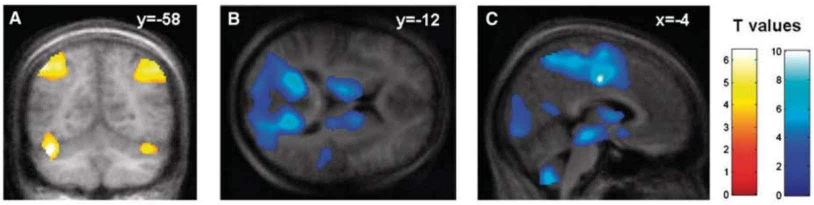

Figure 3. Clear Goals

Activation of bilateral IPS and fusiform face area (A) and a deactivation of the dorsal anterior cingulate cortex (B) and precuneus (C).

Control during the game was another important aspect of flow. Players would have high observed control if they actively explored new content, such as approaching/escaping from enemies, movement to new places on the map, etc. High game control was correlated with activation in visual, cerebellar, thalamic and motor regions, and a deactivation of bilateral temporal poles and bilateral angular gyrus.

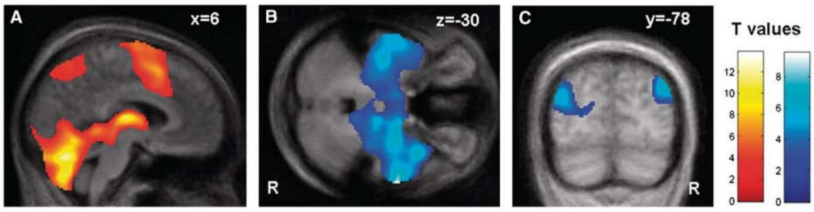

Figure 4. Control

Activation in visual, cerebellar, thalamic and motor regions (A), and deactivation of bilateral temporal poles (B) and the bilateral angular gyrus (C).

Klasen et al. (2011) then overlapped the brain images to test their initial hypothesis that observable factors of flow shared similar neural networks. Excluding the factor of direct feedback, researchers discovered common activations of the paleocerebellum, thalamus, hypothalamus and premotor areas.

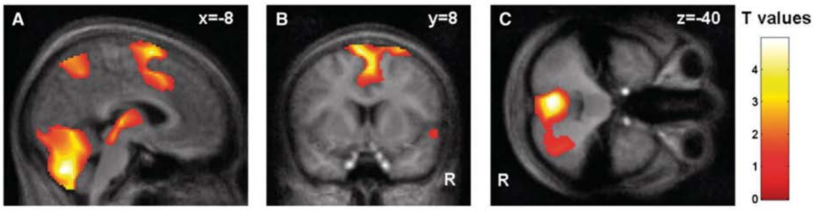

Figure 5. Common Activation of the Paleocerebellum (A), Thalamus, Hypothalamus (B), and Premotor Areas (C) when Brain Images were Overlapped

The research by Klasen et al. (2011) supports the synchronization theory of flow because they demonstrated that the same few regions of the brain are activated when the researchers isolated each element of flow. The activation of the premotor area in the frontal lobe, responsible for the motor plans of voluntary movement, demonstrates higher order experiments posited by the synchronization theory of flow.

Neural Mechanisms of Flow: A Summary

Researchers have sought to find the one true definition of flow, but have come to separate conclusions: brain wave readings from an EEG, the transient hypofrontality hypothesis, and the synchronization theory of flow. Flow itself is a nuanced term. The hypotheses by researchers attempt to simulate the experience of flow, and the nuanced nature of the term allow for various hypotheses to lead to the same experience. The lack of standardized definitions and community agreement hampers the cumulative progress of flow state research, and theories work to disprove rather than support other theories. To enhance the scientific rigor and validity of flow, researchers continue to refine hypotheses and theoretical frameworks and models of flow. Scientists continue to study the neural-mechanisms and causes of flow because the benefits of flow are apparent, and researchers are trying to study why.

Applications of Flow: Maintaining Objectivity

Flow is best known for its applications. Csikszentmihalyi developed the term “flow state” after many people he interviewed described how their optimal experiences occurred when work flowed without much effort (Csikszentmihalyi, 2000).

In studies that seek to understand the performance benefits of flow, researchers use a variety of methods to quantify the flow experiences of the participants.

The main method used to quantify flow is the Flow State Scale (FSS). FSS is given to individuals to identify definitions of flow and to evaluate their own personal experiences during flow-like situations. The original version contained 36 questions designed to provide a description of an individual’s flow characteristics. It uses a self-report policy to measure flow experiences after physical activity (Jackson & Marsh, 1996). The questions followed the nine dimensions of flow described by Mihaly Csikszentmihalyi, with four questions for each dimension. A condensed version also contains nine dimensions, but only one question per dimension. The benefits of FSS is that the questionnaire is quick to fill out and the scale allows researchers to conduct statistical analysis. On the other hand, the drawbacks are that the data is completely self-reported and the questionnaires can only be given after the flow-state experience.

Applications of Flow: Optimizing Professional Performance

Athletes, military personnel, and other demographics with little common ground all claim flow-state increases their concentration and leads to greater performance. To enhance the validity of flow, researchers studied the performance enhancement capabilities of flow in people of varying professions.

Applications of Flow: Sports

Jackson et al. (2008) conducted a qualitative investigation into the flow experiences of professional figure skaters to garner a greater understanding of flow in sports. The researchers interviewed sixteen former US National Champion figure skaters (titles ranging from 1985-1990) on optimal skating experiences. The participants were first asked to describe an optimal skating experience and later questioned about the factors that allowed them to achieve such a flow state. Given a flow questionnaire similar to the flow state scale, the skaters shared many opinions. On a 10-point scale, skaters indicated an average of 9.4 for the question asking if their mind and body worked in greater unison during states of flow. Results from the survey also indicated the skaters were more absorbed in the task at hand and overall enjoyed the experience more (9.3 and 9.6 respectively). It is important to note the skaters were not given the flow questionnaires right after a flow-state experience, rather they were asked to recall past experiences. Furthermore, the particular results of the questionnaire may only pertain to a small sample of elite figure skaters, and may not necessarily be the generalized experience for all athletes.

Applications of Flow: Military

Transcranial Direct Current Stimulation (tDCS) is a noninvasive brain stimulation technique that induces an artificial flow. Participants that have been stimulated for a few minutes have shown increased cognitive functions and working memory by stimulating the left dorsolateral prefrontal cortex (Fregni et al., 2005). In a study by Ulrich et al. (2018), researchers used anodal tDCS, a type of stimulation that increases excitability, to stimulate the medial prefrontal cortex and found an increase in flow for participants experiencing low flow. In a study by the Defense Advanced Research Projects Agency (DARPA), researchers tested the performance of two groups of snipers. In the single-blind experiment, one group had a tDCS stimulation applied to the right temple at 2 milliamps, while the other group had no current. In 30 minutes with the applied current, the experimental group saw a 2.1x improvement in threat and non-threat detection accuracy compared to the control group (Kruse et al., 2008). tDCS is effective for understanding the application and enhancement capabilities of flow because flow cannot be easily quantified. Different people will experience varying levels of flow during the same experience, and tDCS is a way to make such experiences as consistent and precise as possible.

Applications of Flow: Miscellaneous

Mosing et al. (2018) examined 10,000 sets of Swedish twins, and were asked to fill out the Swedish Flow Proneness Questionnaire along with the Emotional Exhaustion subscale of the Maslach Burnout Inventory-General Survey. The researchers determined a weak casual relationship between depressive symptoms and flow proneness (0.43) and between burnout and flow proneness (0.34), suggesting flow may limit emotional distress. In a similar observational study, law graduates who experienced more flow waiting for the bar exam results reported less worry and fewer negative emotions. In another experiment, 309 undergraduate participants engaged in a flow activity, Tetris, while waiting for their peers to rate their physical attractiveness, and a similar mitigation of negative emotions was found (Walsh et al., 2019)

Optimizing the Flow Experience: Introduction

Flow can be characterized with nine key features: challenge and skills balance, action and awareness merging, clear goals, unambiguous feedback, concentration on the task, sense of control, loss of self-consciousness, distorted sense of time, autotelic experience (Csikszentmihalyi, 1990). These nine features indicate a flow experience, and working to improve each individual feature can contribute to the overall flow experience. In the following paragraphs, I will outline both the dimensions of flow that can be optimized to improve the experience and also features that indicate a strong flow experience.

Challenge and Skills Balance

Optimal flow requires an equal balance between challenge and skills. Tasks that are too difficult will be considered impossible, while tasks that are too easy will be boring. Boredom and anxiety are barriers to achieving flow. A task that matches our skill and slightly challenges our limits is one where flow is required to make progress. For example, the process of counting to one million could not induce flow because of the task’s mundane nature. On the other hand, running a marathon without training would belong on the other extreme end of difficulty and also not induce flow. The Yerkes-Dodson Law (Yerkes & Dodson, 1908) suggests an alternative way of thinking about challenge and skills: arousal. Performance increases with mental arousal, but only up to an optimal point. Any additional arousal will only be a detriment to performance. Activities that hover in the optimal range of arousal will be most effective at optimizing the flow experience.

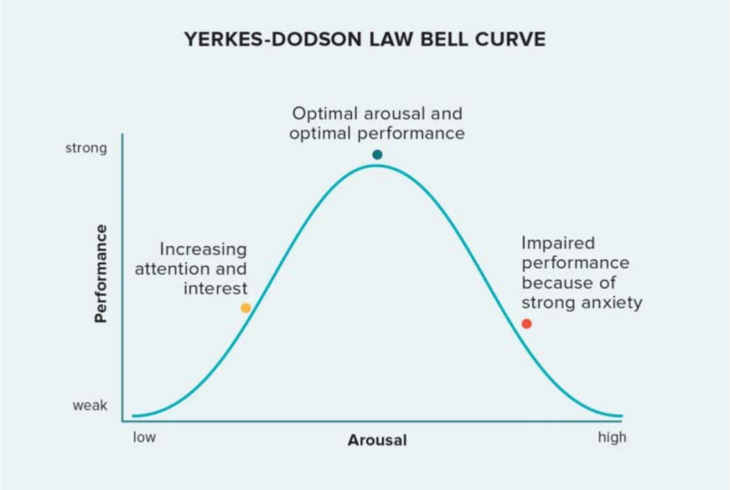

Image found on Google. The Yerkes-Dodson Arousal Curve

Clear Goals

While we cannot directly optimize action and awareness merging, we can set clear goals that improve the merging between action and awareness. To maintain complete attention, the demands of the task must be linear and easy to follow. At any point, a person in flow should not have to stop and question their actions, as that disturbs the experience. Framing the activity is vital towards a clear goal. An example of an unclear goal would be “improve basketball ability”. Although an objective is made, the course of action is vague and unclear. Do I practice shooting, dribbling, or strength training? Even if isolated down to improve shooting ability, does that mean layups, free throws, or three-pointers? A revised, clear goal would be “make 10 free throws in a row”. Not only is the activity specified, the end result is also clear.

Unambiguous Feedback

Unambiguous feedback and clear goals go hand in hand. Flow state is optimized when direct and immediate feedback is always present, so we know how well we are doing, all the time. Setting up clear goals will inherently provide unambiguous feedback for people. All competitive sports induce flow because the players understand that the scoreboard reflects their performance.

Concentration on the Task

Eliminating distractions and the urge to multitask is crucial for triggering flow. Researchers recommend minimizing technology and social media usage because they are highly distracting and make it harder for the brain to focus on the task at hand. An optimized flow state requires the sacrifice of short-term gratification for delayed gratification (Wilcox & Stephen, 2013). When studying for an up-coming test, even the mere presence of a phone or tab on the computer can tempt us, and it requires additional mental energy to regain focus. To eliminate a distraction is to remove it from our senses. Put the phone in another room out of grasp and silence notifications. If a smell or sight cannot be removed, the best option is to remove oneself from the environment for one with fewer distractions. Depending on the activity, distractions can come in various forms.

Autotelic Experience

An autotelic experience is one where the process is self-rewarding, and not necessarily the product. Self-rewarding activities are not done for monetary gain, a grade in school, or other external motivations. Flow is an intrinsically rewarding activity, and many professional athletes and musicians seek flow state for the very same reason.

Indicators of Flow Experience

Action and Awareness Merging

In our everyday lives thoughts wander to all corners of the brain, creating distractions and disturbances. In a flow state, we have complete, undivided attention on the task at hand. Positive flow experience occurs when one’s action and focus centralize on one common goal. This is an indication that distractions have successfully been reduced and minimally impact the task in hand.

Sense of Control

Sense of control is a sensation of freedom. When an appropriate balance between challenge and skill is established, we have the agency to enact change on the status quo. In a game of chess, players are directly in control of the pieces on the board and results are determined by our actions, not luck.

Loss of Self-Consciousness

One becomes so absorbed in the task that they lose their own self-consciousness. Loss of self-consciousness is a product where clear goals and unambiguous feedback can influence such experience. Metacognition disrupts the flow of thought as now our focus on a certain task is interrupted by self-consciousness.

Distorted Sense of Time

Depending on the situation, time will feel slowed down or sped up when one is completely engaged in the moment. A greater distorted sense of time would indicate a greater flow experience. In a flow state, three hours can feel like thirty minutes. Simultaneously, one minute can feel like five.

Conclusion

Experienced by many, understood by few, flow state is often treated as an abstract experience with little to no scientific or tangible basis. Since the introduction of flow theory by Mihaly Csikszentmihalyi in the 1970s, researchers have continued to explore the brain science and performance benefits of such state. Neurological definitions of flow explored in this meta-analysis include specific brain wave patterns, the transient hypofrontality theory, and synchronization theory of flow. It is difficult to establish an agreed upon scientific definition for flow primarily because of the broad and abstract nature of flow, where many different experiences can all be categorized under flow. Although researchers have yet to agree on the precise neural mechanisms of flow, the tangible benefits of flow are heavily supported by studies. From athletes to musicians, and military personnel to students, flow can optimize our performance in all types of work. Beyond detailing the benefits of flow, this meta-analysis also identifies key habits and behaviors that anyone can incorporate in their daily lives to achieve flow.

The real world implications of flow state are immeasurable, allowing humans to be more efficient learners and better creative thinkers. Additionally, flow is not an esoteric phenomenon exclusive to people at the top of their professions. Everyone can optimize a flow state, which makes the benefits tangible and realistic for all. General performance enhancement qualities of flow are known, but the benefits in specific contexts are still unclear. A limitation in all studies surrounding the research of participants in flow is the method scientists use to quantify the experience. Current methods use questionnaires that are given to the participants after a flow inducing activity. Not only does this method rely on the subjective account of each participant, the questionnaires can only be answered after the fact, meaning the participants must try to remember their experiences in the flow state. This limitation is also inextricably linked to the lack of universal agreement on the neural mechanisms of flow. In theory, if an agreed upon mechanism of flow were to be made, researchers could measure that particular region of the brain responsible for flow, and not have to rely on subjective accounts by participants. Flow theory continues to be a heavily researched subject in psychology, and a greater public interest in the topic can further expand the field of flow science.

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