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The role of player's flow in the complex skill learning

PhD Thesis

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Chapeau bas!

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Abstract

Problem

The purpose of the study was to analyze the role of player flow in the process of learning new, complex skills. To achieve this goal, two studies were conducted. Study No. 1 was performed to evaluate the psychometric properties of the Polish versions of the Dispositional Flow Scale-2 (DFS-2) and the Flow State Scale-2 (FSS-2), in order to address the lack of appropriate

tools for studying flow among Polish speakers. Study No. 2 focused on the importance of flow for learning complex new skills in the form of the video game training. It concentrated on three areas: verifying whether a player's level of flow is related to his or her performance in real time strategy (RTS) games as measured by telemetry variables, whether there are behavioral and mental predictors that can identify a player's predisposition to achieve a higher level of flow, and finally, whether the level of flow achieved by a player during training with an RTS game will be related to the training-related changesin a cognitive tasks?

Method

The Study No. 1. included 856 participants, of which 496 participants (women N = 286, men N = 210) were recruited for the DFS-2 tool survey, and 360 participants (women N = 190, men N = 169, others N = 1) for the FSS-2 questionnaire survey. Those who enrolled in the FSS-2 study participated in an online workshop, playing the "Symbols" game, and then completed the FSS-2 questionnaires. In the case of the DFS-2, the task was only to complete the questionnaire.

Study No. 2 - a longitudinal, multi-measurement-points study - was conducted on people recruited to participate in the training project "The temporal dynamics of neurocognitive changes induced by complex task training in the form of strategic computer game". The 29 subjects (women N = 19, men N = 10,) from the initial sample of 73, who had no previous exposure to real-time strategy games and limited experience with action games, completed the study. They trained in one of two groups that differed in the complexity of the training environment: a fixed environment group (FEG) and a variable environment group (VEG). At the beginning of their approximately three-month stay in the project, the participants underwent a series of behavioral, questionnaire, fMRI and EEG tests, and then proceeded to the initial training with a Star Craft II game. After this first training, the

participants practiced the Star Craft II (SCII) game for 60 hours. During the SCII practise participants regularly completed questionnaires measuring flow and task load as well as several cognitive tests. Detailed data about the game performance was also collected. The design of both studies, along with a description of the research procedures, was approved by the SWPS University Research Ethics Committee.

Results

In the Study No. 1. the results confirmed the reliability of the Polish versions of the DFS-2 and FSS-2 scales. The scales are reliable when applied to Polish adults and young adults. In Study No. 2, the analyses confirmed most of the hypotheses, also indicating new directions worthy of further research. Thus, flow levels are related to performance in real-time strategy games (RTS), and some flow state items positively correlate with in-game performance.

Individuals with higher scores on the Dispositional Flow Scale are more likely to experience a flow state when learning complex skills in games. Multivariable regression analysis revealed that higher levels of averaged flow state measured across the whole study and some of its dimensions was consistently associated with lower Neuroticism, indicating a negative impact of Neuroticism on the experience of flow. Openness showed a positive association with Transformation of Time, and negative with Unambiguous Feedback. Neuroticism impacted player performance (PACs per Minute) via mediation by Mean Flow and four flow dimensions, while Agreeableness impacted performance through Mean Flow. Higher Neuroticism was associated with lower scores in flow dimensions and performance, while higher Agreeableness was linked to higher performance but lower Mean Flow. A multivariate regression was run to predict Mean Flow score from Load Index factors (derived from NASA task). Built model turned out to be significant. Task load significantly influenced flow expierience, with higher effort enhancing flow and higher frustration inhibiting it. The study's findings suggest that managing effort and reducing frustration could enhance flow during gameplay.

Measurements of the relationship between flow and cognitive functions (updating memory, task switching, visual motion direction discrimination (VMDD), and reaction inhibition) showed that flow levels experienced during RTS game training are related to cognitive task performance. Higher flow levels and dimension levels correlated with higher accuracy in memory updating. Flow affects task switching in various ways depending on the conditions. In the VMDD task, flow is positively related to accuracy and reaction time.

However, flow does not significantly affect reaction inhibition. Specific dimensions, such as Sense of Control and Loss of Self-Consciousness, influence signal inhibition.

Conclusions

The research described in the tehesis developed a tool for surveying Polish speakers about flow, a psychological state linked to optimal performance. Three further research directions emerged: 1. examining the tool's validity using self-report measures of other psychological constructs; 2. verifying the questionnaire's stability; 3. studying the correlation between the Polish versions of DFS-2 and FSS-2. The longitudinal study suggested a positive link between flow state and game performance, with factors like Challenge-Skill Balance, Unambiguous Feedback, and Sense of Control being crucial. Longer game sessions and increased game difficulty correlated with higher flow levels. The study revealed a significant link between a player's predisposition to flow and their gaming performance. Personality traits, notably Neuroticism and Openness, significantly impacted flow, while intelligence level didn't. Effort and frustration during gameplay also notably influenced flow. Flow and its dimensions varied in their effects on different cognitive tasks, with certain flow dimensions having significant influence.

In summary, presented results allow not only a closer look at flow in the population of Polish-speaking individuals, but also show the impact that the state of flow and/or flow as a trait can have in the process of learning complex skills. Moreover, the results indicate new, noteworthy areas of connections between flow and personality as well as task load. The conclusions from the study can be useful in many fields - from games through education, to building an optimal work environment for development.

key phrases: flow, dispositional flow, video games, cognitive training, video games training, Star Craft II, telemetry, player's personality

Abstrakt

Problem

Celem pracy była analiza roli przepływu gracza w procesie uczenia się nowych, złożonych umiejętności. Przeprowadzono dwa badania. Badanie nr 1 miało na celu przygotowanie polskich wersji Skali Dyspozycyjnego Przepływu-2 (DFS-2) oraz Skali Stanu Przepływu-2 (FSS-2). Uzupełniłyby one braku odpowiednich narzędzi do badania przepływu wśród osób polskojęzycznych. Badanie nr 2 skupiło się na znaczeniu przepływu dla uczenia się złożonych umiejętności w formie treningu gier wideo. Koncentrowało się na trzech obszarach: sprawdzeniu, czy poziom przepływu gracza jest związany z jego wynikami w grach RTS (gry strategiczne czasu rzeczywistego), mierzonymi za pomocą zmiennych telemetrycznych, czy istnieją behawioralne i mentalne predyktory, które mogą zidentyfikować predyspozycje gracza do osiągnięcia wyższego poziomu przepływu, i wreszcie, czy poziom przepływu osiągnięty przez gracza podczas treningu z grą RTS będzie związany z zauważalnymi zmianami w zadaniach poznawczych?

Metoda

Badanie nr 1. objęło 856 uczestników, spośród których 496 uczestników (kobiety N = 286, mężczyźni N = 210) zostało zrekrutowanych do badania narzędzia DFS-2, zaś 360 uczestników (kobiety N = 190, mężczyźni N = 169, inni N = 1) do badania FSS-2. Osoby, które zadeklarowały udział w badaniu FSS-2, wzięły udział w warsztacie online, gdzie grały w "Symbole", a następnie wypełniły kwestionariusze FSS-2. W przypadku badania DFS-2 zadaniem było tylko wypełnienie kwestionariusza.

Badanie nr 2 - badanie podłużne, z wieloma punktami pomiarowymi - obejmowało osoby zrekrutowane do udziału w projekcie grantowym: *"Zmienność w czasie neuropoznawczych efektów treningu złożonym zadaniem w formie strategicznej gry komputerowej."* Badanie - w grupach treningowych, które były objęte badaniem flow- ukończyło 29 osób (kobiety N = 19, mężczyźni N = 10) oraz 12 osób z biernej grupy kontrolnej, nie uwzglednionepoczątkowej puli 73 osób zaproszonych do badania, które nie miały wcześniejszego kontaktu z grami strategicznymi w czasie rzeczywistym i miały ograniczone doświadczenie z grami akcji. Trenowali oni w jednej z dwóch grup, które różniły się złożonością środowiska treningowego: grupa o stałym środowisku (FEG) i grupa o zmiennym środowisku (VEG). Na początku około trzymiesięcznego udziału w projekcie, uczestnicy przeszli serię testów behawioralnych, kwestionariuszowych, fMRI i EEG, o czym

przystąpili do treningu Star Craft II (60 godzin). Podczas treningu uczestnicy regularnie wypełniali kwestionariusze mierzące przepływ i obciążenie zadaniem. Zebrano także szczegółowe dane telemetryczne z gry. Projekt obu badań, wraz z opisem procedur badawczych, został zatwierdzony przez Komisję ds. Etyki Badań Naukowych Wydziału Psychologii Uniwersytetu SWPS w Warszawie

Wyniki

Wyniki badania nr 1. potwierdziły rzetelność polskich wersji skal DFS-2 i FSS-2 dla dorosłych i młodych dorosłych osób polskojęzycznych. W badaniu nr 2. analizy potwierdziły większość hipotez, wskazując także na nowe kierunki dalszych badań. Przede wszystkim okazało się, że poziomy przepływu są związane z wynikami osiąganymi w grach strategicznych w czasie rzeczywistym (RTS), a niektóre elementy stanu przepływu szczególnie pozytywnie korelują z wynikami w grze. Osoby z wyższymi wynikami na Skali Dyspozycyjnego Przepływu są bardziej skłonne doświadczać stanu przepływu podczas uczenia się skomplikowanych umiejętności w grach. Wielozmiennowa analiza regresji wykazała, że wyższe poziomy średniego przepływu i niektóre z jego wymiarów były konsekwentnie związane z niższym neurotyzmem, wskazując na negatywny wpływ neurotyzmu na doświadczenie przepływu. Otwartość na doświadczenia wykazywała pozytywne powiązanie z transformacją czasu, a negatywne z informacją zwrotną. Neurotyzm wiązał się z wynikami gracza (PAC na minutę) i ten związek wyjasniany był poziomem odczuwanego przepływu (mediacja), natomiast ugodowość wiązała się z uśrednionymi wartościami przepływu. Wyższy neurotyzm był związany z niższymi wynikami w wymiarach przepływu i osiągnięciami w grze, podczas gdy wyższa ugodowość była związana z wyższym przepływem i wyzszymi wynikami w grze, ale niższym średnim przepływem. Kolejna wielozmiennowa analiza regresji została przeprowadzona w celu wyjaśnienia uśrednionego wyniku przepływu na podstawie czynników utworzonych z zadania NASA, którym wielokrotnie dokonywano pomiaru obciązenia zadaniem. Zbudowany model okazał się istotny. Obciążenie zadaniem znacząco wpływało na odczuwanie przepływu, przy czym większy wysiłek zwiększał przepływ, a większa frustracja go hamowała. Wyniki badań sugerują, że zarządzanie wysiłkiem i redukcja frustracji mogą zwiększyć przepływ podczas gry. Pomiary związku pomiędzy przepływem a zadaniami poznawczymi (aktualizacją pamięci, przełączaniem między zadaniami, dyskryminacją kierunku ruchu [visual motion discrimination, VMDD], i hamowaniem reakcji) wykazały, że poziomy przepływu osiągnięte podczas treningu z grą RTS są związane z wynikami zadań poznawczych. Wyższe poziomy przepływu są związane z poprawą dokładności w zadaniach aktualizacji pamięci. Przepływ wpływa na przełączanie między zadaniami na różne sposoby w zależności od warunków. W zadaniu VMDD przepływ jest związany z dokładnością i czasem reakcji. Jednak przepływ nie wpływa znacząco na hamowanie reakcji. Specyficzne wymiary, takie jak poczucie kontroli i utrata samoświadomości, wpływają na procesy hamowania.

Wnioski

Sumując, opracowano narzędzie do badania przepływu wśród polskojęzycznych respondentów. Badanie podłużne sugeruje pozytywny związek między stanem przepływu a wynikiem gry, przy czym takie czynniki jak równowaga wyzwanie-umiejętność, jednoznaczne informowanie zwrotne i poczucie kontroli są kluczowe. Dłuższe sesje gry i zwiększenie trudności gry korelowały z wyższymi poziomami przepływu. Badanie ujawniło znaczący związek między predyspozycją gracza do przepływu a jego wynikami w grach. Cechy osobowości, szczególnie neurotyzm, ugodowość i otwartość, wpływały na przepływ i wyniki. Obciążenie zadaniem wpływało na przepływ, a zarządzanie wysiłkiem i redukcja frustracji mogą zwiększyć przepływ podczas gry. Poziom przepływu był związany z wynikami zadań poznawczych.

Wyniki badań pozwalają nie tylko na bliższe przyjrzenie się przepływowi (flow) w populacji osób polskojęzycznych, ale także pokazują wpływ, jaki stan flow lub/i flow jako cecha mogą mieć w procesie nauki złożonych umiejętności. Ponadto rezultaty wskazują na nowe, warte uwagi, obszary powiązań między flow a osobowością oraz obciążeniem zadaniem. Wnioski z badania mogą być przydatne w wielu dziedzinach - od gier poprzez edukację, aż po budowanie optymalnego dla rozwoju środowiska pracy.

frazy kluczowe: flow, przepływ, gry video games, trening poznawczy, Star Craft II, telemetria, osobowość gracza

1. Introduction

The 21st century offers an unprecedented abundance of opportunities, among which - given the limited time of human life - we are trying to find our way. The consequences of this multiplicity are complex. The question of whether to play or not to play no longer requires an answer. Hence the search for mechanisms of functioning that will allow us to immerse ourselves in what we choose without a sense of loss and enjoy it fully, peacefully and without guilt. The holy grail of this search, one of the most positive and satisfying mental states, is flow (Jackson & Csikszentmihalyi, 1999), or the experience of being completely absorbed in the present activity, realized with a sense of lightness (effortlessness) and pleasure (Csikszentmihalyi & Lefevre, 1989). The person experiencing flow is focused, present in the here and now. Positive psychology's search has focused mainly on how this state can serve well-being and enrich people's lives (Csikszentmihalyi, 2000). Challenges generated by civilization changes over the past decades are expanding this area. Understanding the specifics of flow emergence, related to functional characteristics (motivation, sense of focus, self-confidence, among others), may be one of the answers to the question of how to manage one's own performance more effectively (Harris et al. 2021, Landhäußer & Keller, 2012), to switch off from activities other than the one chosen at a given moment - to the benefit of oneself and the tasks at hand. Flow can apply to a variety of life domains, but in the context of performance it has been studied most often in sports (Swann et al., 2016, 2017, Jackson & Kimiecik, 2008, Sinnamon et al., 2012), less often in music, chess, dance (Csíkszentmihályi and Larson, 1987, Csíkszentmihályi and Csíkszentmihályi, 1992, Csíkszentmihályi, 1993, 2000, 2014), or more recently also in the context of video games (Nah et al., 2014, Engeser & Rheinberg, 2008, Keller & Blomann, 2008, Campbell et al., 2018, Pedraza-Ramirez et al., 2020). Sports and video games combine demands on perceptual, attentional and motor skills. While sports are primarily based on physical activity, video game research offers hope for a improvement transfer, where the flow-performance relationship may apply to domains other than those based on physical exertion (Harris et al. 2021). Moreover, the issue of the specificity of computer games cannot be overlooked. Sports are available to everyone, but the effort required to put into them is sometimes disproportionate to the reward, which for many people is too high a threshold for entry. Meanwhile - often for these same people - the game rewards disproportionately to the effort. As a result, the game is an entity that can quickly seize the player, remaining incomprehensible and inaccessible to non-players. It is not surprising, therefore, either the drastic pace of development of the game market (Limelight

Networks, 2020, Acland 2020), or the fact that here, too, researchers - from psychologists to economists - are interested in trying to tease out answers from the game vs. player relationship, regarding the nuances of flow as knowledge that could become an element of rapid and powerful impact, including in fields far removed from games. Current research on games in the context of flow focuses specifically on 3 thematic areas: flow theory per se (Cowley et al., 2008, Su et al., 2016), addiction (Young 2017, Kuss 2013), and gamification, i.e. the application of game elements in non-game contexts (Deterding et al., 2011, Acland 2020). Regardless of the specific area of research, existing knowledge about the sources of flow and its effects, among other things, the flow-performance relationship does not provide clarity on either the strength, manner, or causal direction of the processes involved in the flow relationship (Moran & Toner, 2017, Swann et al., 2018). Given the potential for the weight of conclusions - both scientific and economic, e.g., what are the components of perfect performance (Swann et al., 2017), or whether flow can become the basis for interventions in sports (Aherne et al., 2011, Nicholls et al., 2005), the need for an analysis focused on both studying the history of flow and its directionality is indicated (Harris 2012).

This dissertation aims to present the results of a study of flow in subjects undergoing long-term training of the Star Craft II game. This study focused on the role of the player’s flow in the process of a complex skill learning. The general scheme and content map of the dissertation are presented below.

Dissertation map

The first chapter "*From Magic to Metrics*" is a **literature review**, particularly of the literature dealing with the phenomenon of flow itself, but also studies of the phenomena of video games and players, with a particular focus on studies centered around cognitive functionning. Another element is a description of the process and results of **validation** of the PFSS-2 and PDFS-2 tools (Study I.), prepared by the author of the dissertation as the first flow measurement questionnaire in the Polish language.

The structure of Study 2. centered around the role of the player flow in learning complex skills during a video game consists of two main elements: a common part, setting the context and describing the elements connecting each element of the study, and part separated according to the three research objectives. **Methodological** section includes a description of the **study design**, including its overall goal, objectives, design, **participants** along with a description of the recruitment process, a general description of the concept, concerning the part of the project that focused around the importance of flow to develop complex skills in the game, research **Materials**, (information about the questionnaires, measurement tools, tests, etc. that were used in the study), **Procedures** (description of the procedures used in the study, information on data collection, instructions to participants, experimental procedures) and **Data Analysis** (description of the statistical methods used to analyze the data, including detailed information on specific statistical tests, software used for analysis, and data quality control methods). **Results** section was built around each of the **3 research objectives.** The conclusions from these analyses, relevant to all three research inquiries, were consolidated in the **Discussion** section. This synthesis provided a foundation for drawing the final **Conclusions**, followed by a section describing the **Limitations**. The dissertation closes with **Bibliography**. A set of **Appendices** has been appended to the dissertation, which, for the sake of clarity of the argument, have not been included in the main text, but may be an interesting addition to the content.

2. From magic to metrics - the development of flow research

The term flow functions in everyday language to mean acting with lightness, without effort, giving a sense of pleasure. It is associated with a variety of activities, from the consumption of food or drink to the effort put into study or work. In Polish, the word is found in its original form, although there is a Polish equivalent - *przepływ*. *Flow* is a short and easy word, *przepływ* is a longer word and one can make a spelling mistake - perhaps that's why it didn't catch on. Flow attracts the idea of an effect without overwhelming and all-desired hard work. It might seem that such a common and obvious phenomenon would not pose definitional difficulties. However, it turns out that there is a rather significant difference between the popular "What a flow!" and what science understands by flow - and therefore what is being studied.

2.1. The Essence of Flow

The origin of flow research and theory was the desire to understand the phenomenon of intrinsically motivated or autotelic activity, that is rewarding in itself (Greek: auto = self, telos = goal), regardless of its consequences or end product. Subsequent reports have, in fact, identified flow as a very practical application, the clue of which is the relationship between the experience of flow and performance (Csikszentmihalyi, Abuhamdeh & Nakamura, 2005, Engeser & Rheinberg, 2008, Jin, 2012, Keller & Bless, 2008, Landhäußer & Keller, 2012, Peifer et al., 2014). It has been shown that flow as a state of high concentration and a sense of control can actually motivate subjects to improve performance (Engeser & Rheinberg, 2008, Jin, 2012, Landhäußer & Keller, 2012). Csikszentmihalyi himself became interested in this phenomenon while studying the creative process in the 1960s (Getzels & Csikszentmihalyi 1976). He was amazed by the fact that an artist - concentrated and in complete control - would first work assiduously on a painting, disregarding hunger, fatigue and discomfort, only to quickly lose interest in the work once it was completed. The term flow was coined while studying the nature and conditions of pleasure, during interviews with chess players, climbers, dancers, or surgeons, when some subjects used the metaphor of a current that lifted them effortlessly to describe their experience in the study. (Csikszentmihalyi 1975, 2000). The subjects described a subjective state in which they are completely engaged in an activity, feeling satisfaction and joy in the process. The reported phenomenology was remarkably similar in both play and work settings.

Under certain conditions, almost everything, at work and at play, is able to trigger the experience of flow, but Csikszentmihalyi identified three conditions of key importance. First - a **clear set of goals** whose value lies in their ability to structure the experience by directing attention. Second - a **balance between perceived challenges and perceived skills**, whereby - unlike in the concept of "optimal arousal" (Berlyne 1960, Hunt 1965) at the phenomenological level, what matters is the perception of requirements and skills, not their objective presence. When perceived challenges and skills are well matched they completely absorb attention. This one, however, is inherently fragile: if challenges outweigh skills, a person becomes restless and eventually succumbs to frustration, while if skills outweigh challenges, a person relaxes and eventually becomes bored. These subjective states provide feedback on the changing relationship with the environment and force the individual to adjust behavior to escape the more aversive subjective state and re-enter the flow. Third, flow depends on the presence of **clear and immediate feedback**, informing the individual how he or she is doing and directing him or her to sustain or modify the course of action. Because flow occurs at a high level of challenge, feedback is sometimes critical, which is not to say that it is detrimental to commitment to the task, such as a pianist practicing with a metronome, rehearsing video or audio recordings prior to public speaking. In summary, clear goals, optimal challenges and clear, immediate feedback are essential to induce the intrinsically satisfying, experiential engagement that characterizes flow. These are not the only factors that influence the degree of engagement in an activity. They can also be influenced by: the importance a person attaches to performing an activity well (Greenwald 1982, Harackiewicz et al. Elliot 1998, Harackiewicz and Manderlink 1984), congruence between task-specific and higher-order goals (Harackiewicz and Elliot 1998, Rathunde 1989, Sansone et al. 1989), the personal implications an individual attributes to success or failure in an activity (Mueller and Dweck 1998), autonomy orientation (Deci and Ryan 1985), and absorption (Tellegen and Atkinson 1974), a construct used to measure susceptibility to hypnosis and conceptually related to openness to experience (Glisky et al. 1991, Levin and Fireman 2001, Wild et al. 1995).

If the underlying conditions are maintained, i.e., clear goals, balanced challenges, and clear, immediate feedback, a person's experience can unfold smoothly from moment to moment, and the person enters a subjective state that is characterized by: **positive affect, focus, spontaneous action, total immersion in the activity being performed, a sense of control over the situation, loss of self-awareness, distortion of time** (feeling that time is passing faster than normal), and experiencing the activity as intrinsically satisfying (Csikszentmihalyi, 1982, Csikszentmihalyi & Csikszentmihalyi, 1988).

2.2. Flow, Motivation and Awareness

According to Csikszentmihalyi the phenomenological experience of flow is a powerful motivating force. Individuals maximally engaged in an activity tend to find it pleasurable and intrinsically rewarding. Regardless of the initial motivation, activities will not continue if they are not enjoyable or if people are not motivated by extrinsic rewards.

According to the traditional approach, intrinsic motivation is supported by a **sense of competence and efficacy** (Deci 1971, Elliot et al. 2000, Fisher 1978, Harackiewicz 1979, Ryan 1982, Vallerand and Reid 1984). Csikszentmihalyi suggests that although perceived competence appears to be an important prerequisite for intrinsic motivation, many of the rewards of intrinsically motivated behavior come from the experience of preoccupation and interest embodied in the flow, e.g., a person is initially indifferent or bored with an activity, such as listening to classical music or playing a computer game. Then, as the opportunities for the activity become clearer or as the individual improves his or her skills, the activity becomes interesting and eventually enjoyable. In this sense, the rewards for such intrinsically motivated activities are "emergent." This is the phenomenon of **emergent motivation**, meaning that we can experience a new or previously unengaging activity as intrinsically rewarding if we find flow in it. The motivation here comes from the experience itself. What happens next is a response to what happened immediately before, within the interaction. It is not conditioned by a pre-existing intentional structure located in the person (e.g., goal, drive) or environment (e.g., beliefs, rules) (Csikszentmihalyi and Nakamura 1999).

The ability to enjoy challenges and then cope with them is a fundamental meta-task that is essential for individual development and cultural evolution, but many obstacles prevent individuals from experiencing the flow. In fact, a growing body of research suggests that excessive concern for security, comfort and material well-being is detrimental to optimal development (Csikszentmihalyi and Hunter 2003, Kasser and Ryan 1993, Schmuck and Sheldon 2001). Therefore, understanding how flow works is essential for those interested in improving the quality of life on a subjective or objective level (Csikszentmihalyi 2014).

To explain the experience of flow Csikszentmihalyi referred to a broader model of **consciousness, experience and the self,** developed in conjunction with the concept of flow (1988). According to this model, individuals are exposed to an excessive amount of information, and consciousness is a complex system for selecting, processing and storing this information. Information appears in consciousness through the selective investment of attention, which includes all cognitive, motivational and emotional processes of consciousness. The memory system stores and retrieves this information, and subjective experience can be regarded as the content of consciousness. The ego emerges when consciousness arises and becomes aware of itself as information about the body, subjective states, past memories and personal future. Consciousness provides a measure of control, freeing the person from total submission to the dictates of genes and culture, thus introducing the alternative of rejecting them rather than conforming. Consciousness thus serves as "the coupling between programmed instructions and adaptive behavior" (Csikszentmihalyi and

Csikszentmihalyi 1988, p. 21).

Csikszentmihalyi emphasized the impact of attentional processes on the experience of a limited human being whose choices are critical because attention is finite and narrows the amount of information that can be processed in consciousness. Attention therefore plays a key role in entering a state of flow and remaining in it. Entering flow is a consequence of how attention was focused in the past and how it is focused in the present by the conditions of action. Interests developed in the past will direct attention to specific challenges. Clear goals, immediate feedback and manageable levels of challenge direct the person so that attention is completely absorbed by the stimuli defined by the activity. Attention is completely invested in the current exchange. Action and consciousness merge in the absence of free attention to allow objects outside the direct interaction to enter consciousness. The passage of time becomes distorted. The consequences i.e. apathy, boredom and anxiety, or flow reflect the organization of attention at any given time. When attention shifts to oneself and one's shortcomings - especially in the context of extrinsic motivation - it creates self-consciousness that makes it difficult to engage in challenges.

2.3. Induce flow. Easy to say

There is no set of challenges that connect to flow and those that do not. What can become a flow activity depends on the subjective experiences and perceptions of the individual. Thus, walking down the stairs is an imperceptible means to an end for most people, but for a person on a skateboard it can be an opportunity to achieve flow. This state leads this individual to seek replication of the flow experience, which promotes development. Development is possible if the level of challenge corresponding to the opportunity increases - so while for a beginning skateboard enthusiast the challenge will be stairs, in subsequent steps he will look for steeper stairs, varied with barriers, etc. The motivation to continue or return to an activity comes from the experience itself.

According to the initial theories, the ability to experience flow might seem to be universal, but **people differ in the frequency with which they experience flow**. Csikszentmihalyi (1975, 2000) recognized the possibility of the existence of an **autotelic personality**, that is, a person who tends to enjoy life or "generally does things for their own sake, rather than to achieve some later external goal" (Csikszentmihalyi 1997, p. 117). This type of attitude, according to the researcher, is characterized by curiosity, interest in life, perseverance and a low level of egocentrism, resulting in the ability to be motivated by intrinsic rewards. Later studies considered time spent in a state of flow as a measure of flow propensity (AdlaiGail 1994, Hektner 1996), as well as intrinsic motivation in situations with high levels of challenge and skill, which was to be reflected in low average scores on the item "I would like to do something else" when subjective challenge and skill were above average (Abuhamdeh 2000, Csikszentmihalyi and LeFevre 1989). The attractiveness of the consequences of high autotelicity, e.g., more better-defined goals, more positive cognitive and affective states (Adlai-Gail 1994), better academic performance (Adlai-Gail 1994, Wells 1988), greater involvement in passions (Csikszentmihalyi et al. 1993), lower stress and tension (Abuhamdeh 2000), and fewer inclinations to break the law (Schmidt 2000) have led researchers to look for the source of the autotelic personality. Rathunde (1988, 1996) showed that it is shaped in the family environment, which he called "complex," providing both support and challenge, control and positive feedback, more positive experiences of productive activities (such as learning).

2.4. Flow conceptualizations

The original definition of the flow state has proven to be reliable and confirmed by research. It was found to be consistent regardless of cultural, socioeconomic, gender and age differences, as well as the nature of the activity performed. Research on the flow concept continued in the 1980s and 1990s by Csikszentmihalyi and colleagues (e.g., Csikszentmihalyi and Csikszentmihalyi 1988, Inghilleri 1999, Massimini and Carli 1988, Massimini and Delle Fave 2000).

Given the ephemeral nature of flow, it seems interesting how it can be measured especially when we take into account that the concept of flow emerged from qualitative interviews on the nature of experience (Csikszentmihalyi 1975/2000). Elite athletes (Jackson 1995) or writers (Perry 1999), among others, have been studied in this way. While the purpose of interviews was to capture the nature of flow, questionnaire studies were used to measure dimensions of the experience of flow and/or differences in its occurrence in different contexts or individuals (Csikszentmihalyi and Csikszentmihalyi 1988). Later research on flow gained momentum with the Experience Sampling Method (ESM) (Csikszentmihalyi and Larson 1987), focused on sampled moments in which there were equation-based challenges-skill conditions for flow and/or flow was reported at all. Flow was typically measured by summing self-reported levels of concentration, engagement and enjoyment. The first mapping of the phenomenological landscape in terms of perceived challenges and skills identified three regions of experience (Csikszentmihalyi 1975, 2000): a. the flow channel along which challenges and skills matched, b. the area of boredom, when opportunities for action relative to skills diminished, and c. the area of anxiety, when challenges increasingly exceeded opportunities for action. This mapping was based on the original descriptions of deep flow (see Fig. 1).

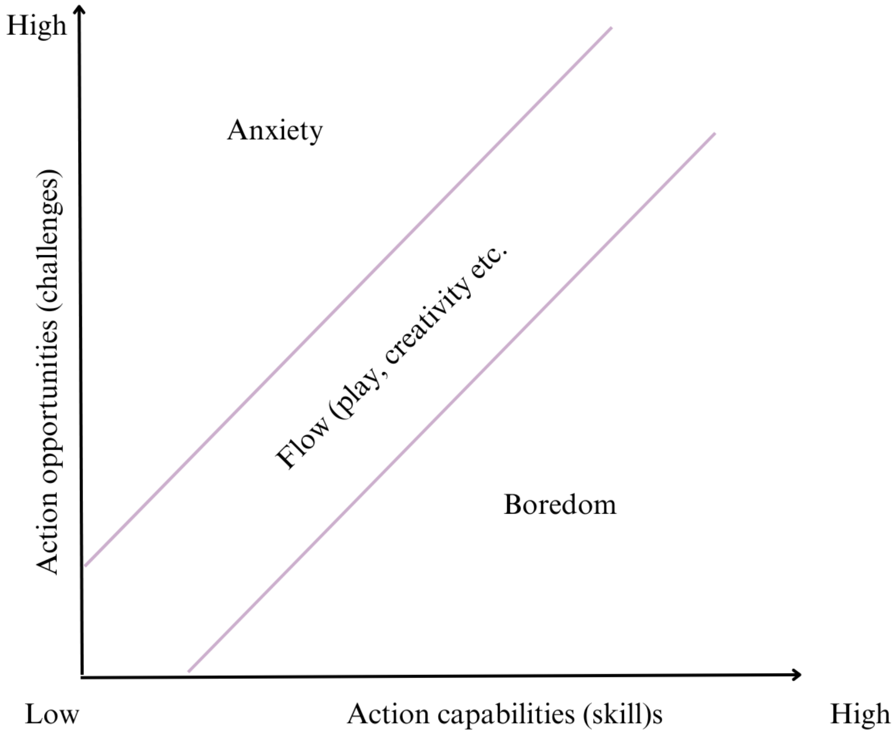


Figure 1. The original model of flow state. Flow is experienced when perceived opportunities for action are in balance with the person's perceived skills. Adapted from Csikszentmihalyi (1975, 2000)

Initial analyses of ESM data, however, were not consistent with this mapping. Balancing challenges and skills alone did not optimize the quality of experience because it did not account for the dynamics of skill development. Activities where low skills are combined with low challenges (e.g., watching movies) do not lead to flow (Kubey and Csikszentmihalyi 1990). Thus, they redefined flow as a balance between challenges and skills when both are above the average level for a person. That is, flow should occur when individuals perceive greater opportunities for action than those they encounter on average in their daily lives, and have the skills to take advantage of them. This shift has led to a significant reformulation of the phenomenological map, revealing a fourth state, apathy, associated with low challenges and correspondingly low skills. Experientially, this is the realm of stagnation and diffusion of attention, the opposite of the flow state. Consequently, the challenge/skill map was differentiated into eight experimental channels instead of four quadrants (see Figure 2).

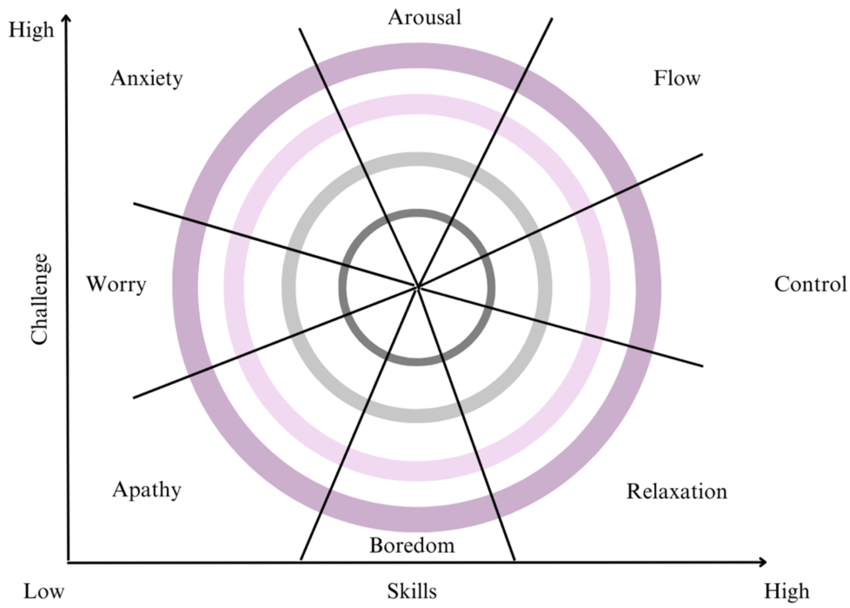


Figure 2. The developed model of the flow state. Flow is experienced when perceived challenges and skills are above the person's average levels, when they are below, apathy is experienced. Intensity of experience increases with distance from the person's average levels of challenge and skill, as shown by the concentric rings. Adapted from Csikszentmihalyi (1977).

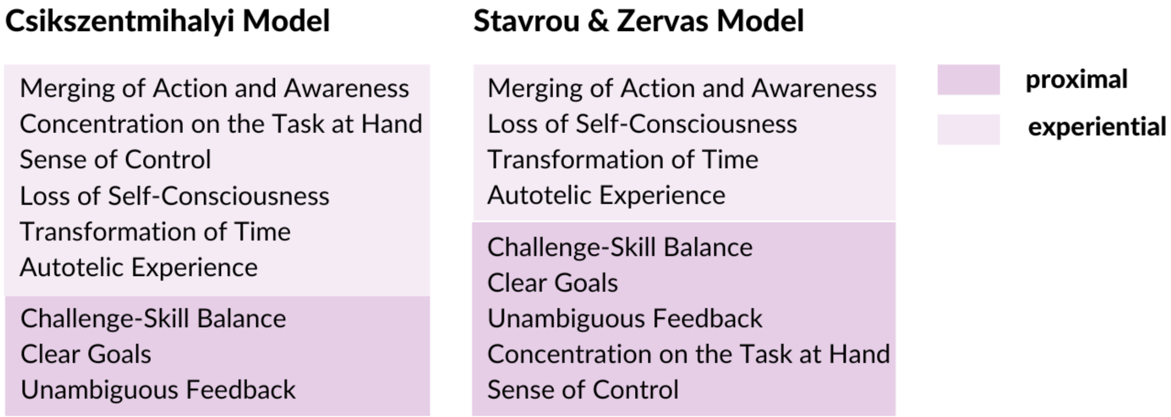
The quality of experience intensifies within a channel or quadrant as challenges and skills move away from a person's average levels. Operationally, the challenge/skill space is divided into a series of concentric rings as the intensity of the experience increases. The researcher may choose to focus only on the outer rings of the flow channel, theoretically in the region of deep flow experiences described in the early interviews. In summary, according to the traditional concept of flow, it includes nine basic dimensions:

Dimension Name	Dimension Description
Challenge-Skill Balance (1)	Flow requires a balance between skill level and challenge. If the challenge is too demanding, it can generate anger, and if too easy, boredom. In the flow experience we feel engaged in the challenge but not overwhelmed.
Merging Action and Awareness (2)	In the flow state we are completely absorbed in the task at hand. We do not think about anything else, there are no "escaping thoughts".
Clear Goals (3)	In many everyday situations there are conflicting demands, and sometimes we don't know what should occupy our attention. However, in the flow experience, we have a clear goal and have a good understanding of the situation.
Unambiguous Feedback (4)	In the flow state we know how well we are doing. We are accompanied by direct and immediate feedback, thanks to which we are able to constantly monitor and adjust our reactions to current requirements.
Focus on the Task at Hand (5)	A high level of concentration narrows our focus, shutting out any unnecessary distractions. We are preoccupied with the activity, we are only aware of what is relevant to the task at hand and we do not think about unrelated things.
Sense of Control (6)	There is an absolute sense of personal control, as if we can do anything we want.
Loss of Self-Consciousness (7)	Lack of awareness of bodily needs as self-awareness fades. We often spend a lot of mental energy monitoring how we look in the eyes of others. In a state of flow, we are too involved in action to care about protecting our ego.
Transformation of Time (8)	A distorted sense of time emerges. We do not notice it. Time either slows down or flies by when we are fully engaged in the moment.
Autotelic Experience (9)	Flow is an intrinsically satisfying activity, the activity becomes autotelic, it is an end in itself, done for its own sake.

In this study, the above flow dimensions constitute a group of basic variables. They are labeled according to the traditionally accepted order and always - for the sake of order - appear together with a number denoting this order.

According to the traditional view, of the nine flow-building dimensions, three are

proximal or initial conditions of experience, and six describe the **experiential** (Kawabata & Mallett, 2011, Nakamura & Csikszentmihalyi, 2002). The proximal conditions are: a **challenge-skill balance (1)** (i.e., an assessment that the demands of the activity match the person's capabilities), **clear goals (3)** and **unambiguous feedback (4)** on the effects of the activity. The **experiential** components of flow are: **a combination of action and awareness, focus on the task, a sense of control, loss of self-awareness, time transformation and autotelicity** (experiencing the activity as intrinsically satisfying).



An **alternative conceptualization by Stavrou and Zervas** (2004) proposes a different arrangement. They analyzed Csikszentmihalyi's original proposition and also found that, from a theoretical point of view, the subscales of the Flow Scale can be divided into two main categories that have different effects on the quality of flow experience in athletes. But in their proposal, the **proximal** category includes five factors: **balance between challenge and skill, clear goals, clear feedback, focus on the task, and a sense of control.** These factors can be characterized as precursors to the experience of flow, as their existence can induce flow. The second category includes four factors: **the merging of action with consciousness, the loss of self-awareness, the transformation of time and the autotelic experience**, which are perhaps the **consequences of entering flow**. In other words, the precursors of flow experience are important for entering the flow, while the consequences are valuable for maintaining the flow state. The their study raised several questions related to model modification, regarding the possibility of introducing additional or alternative flow characteristics on the Flow State Scale. Although the nine-factor structure of the Flow State Scale was developed based on a sound theoretical framework, and the factor analysis of the tool supported this structure, there are some flow experience characteristics that should be omitted and others included. For example, a dimension worth treating differently is **time transformation (**Stavrou & Zervas 2004)**.** This factor showed positive correlations with anxiety, negative correlations with confidence, and low intercorrelations with Flow State Scale subscales. Stavrou and Zervas emphasize that time can be experienced extremely differently as a negative, neutral or positive trait. The lower correlations of time transformation with the other subscales of the Flow State Scale indicate that athletes, the authors write, may perceive this factor as an illiquid trait, unrelated to performance in sports. Moreover, the occurrence and positive evaluation of time transformation depends on the specifics of the task, such as the type of sport. There are disciplines, i.e. fencing and table tennis, in which a sense of time is not necessary in high performance (Jackson 1996). However, in the disciplines, i.e. athletics, cycling, archery, shooting, gymnastics, or finally dance, it is essential, serving as a checkpoint of an athlete's performance, or a dancer's or musician's benchmark (Karageorgis, Terry, & Lane, 1999, Vlachopoulos et al., 2000). Thus, a sense of time may be a necessary condition or at least an important feedback. Therefore, a person can enter a state of flow while performing an activity with a total sense of time, which deviates from the traditional Csikszentmihalyi interpretation.Each dimension of Flow State Scale affects the participant's task performance and experience differently.

2.5. Tools used in subsequent flow studies

As I mentioned earlier, flow has been studied mainly in sports, music, chess, dance (Csíkszentmihályi and Larson, 1987, Csíkszentmihályi and Csíkszentmihályi, 1992, Csíkszentmihályi, 1993, 2000, 2014), or recently also in the context of video games (Engeser and Rheinberg 2008, Nah et al.,2014, Baumann et al. 2016, Chen and Sun 2016, Cowley et al. 2019, Harris et al. 2019 etc.).

Since the beginning of flow research, the most popular form of research has been self-descriptive. Currently, researchers are continuing to search and construct testing of measurement tools most relevant to flow measurement. These include: The Flow Questionnaire (Nakamura and Csíkszentmihályi, 2009, Moneta, 2012), Experience Sampling Method (ESM) (Nakamura and Csíkszentmihályi, 2009, Moneta, 2012, Csíkszentmihályi and Larson, 2014), Flow State Scale-2 (FSS-2), Dispositional Flow Scale-2 (DFS-2) (Jackson and Eklund, 2002, Moneta, 2012), Flow Short Scale (Delle Fave et al., 2011b, Engeser, 2012), Flow Scale Mayersa (Nakamura and Csíkszentmihályi, 2009), Optimal Experience Survey (Cuestionario de Experiencia Óptima, CEO) (Delle Fave et al., 2011a).

The most frequently used and approved are the Dispositional Flow Scale-2 (DFS-2) and the Flow State Scale (FSS-2) (Kawabata et al., 2008). For their study of sport and physical activity, Jackson and Marsh (1996) transformed Csikszentmihalyi's nine-factor flow model into the Flow State Scale (FSS). Composed of 36 questions, the FSS was designed to assess the experience of flow during a specific activity, with data collected immediately after the activity (Jackson and Marsh, 1996).

Flow as a trait and tendency to experience flow was measured by the Dispositional Flow Scale (DFS), which is an extension of the Flow Trait Scale (TFS), also developed for measurement among athletes (Jackson et al., 1998). The DFS is a dispositional measure of flow and is used to assess the typical frequency of experiencing flow during participation in a particular activity.

The results of preliminary analyzes of the psychometric properties of the original DFS and FSS showed that both tools showed a satisfactory level of factor validity (Jackson and Marsh, 1996, Marsh and Jackson, 1999) and reliability (0.72–0.91 for FSS and 0.70–0.88 for DFS, Jackson et al., 1998). Middleton et al. (2004) also reported an acceptable reliability (0.71– 0.86) of DFS.

Reacting to the fact that some items in the original tool did not give satisfactory results (from a conceptual and/or statistical point of view), Jackson and Eklund (2002) revised both tools, replacing the problematic items and developed new versions of the flow scales: Flow State Scale-2 (FSS-2) and Dispositional Flow Scale-2 (DFS-2). Nine-dimensional conceptualization of flow, and the nine-factor structure was supported by confirmatory factor analyses (Jackson and Eklund, 2002). The higher order model, representing the global flow construct, also received reasonable support from confirmatory factor analysis (CFA).

For the nine subscales of the DFS and FSS adequate reliability has been demonstrated, with the exception of time and self- awareness, which showed lower internal consistency (Jackson and Marsh, 1996, Marsh and Jackson, 1999, Tenenbaum et al., 1999, Kawabata et al., 2008, Gouveia et al., 2012). Finally, Jackson et al. (2008b) published FSS-2 and DFS-2 in two versions: a. a long version with 36 items, divided equally into nine factors, corresponding to the nine dimensions of Csíkszentmihályi (1990) and b. a short version consisting of nine items, one for each dimension.

FSS-2 and DFS-2 have been translated and validated in various languages, especially often in the context of sports (Doganis et al., 2000, Fournier et al., 2007, Calvo et al., 2008, Kawabata et al., 2008, Gonzalez-Cutre et al., 2009, Gouveia et al., 2012, Crust and Swann, 2013, Riva et al., 2017, Nojavan et al., 2017), but also learning, recreation, well-being (Whitmore and Borrie, 2005, Asakawa, 2010, Rufi et al., 2014, Souza Costa Correia et al., 2020), gameplay and internet games (Wang et al., 2009, Procci et al., 2012, Hamari and Koivisto, 2014), mental diseases (Huang et al., 2019).

It's worth emphasizing that despite a significant interest in the subject, there were no tools for studying flow among Polish-speaking individuals. Therefore, the first step in our work had to be to prepare such a tool, which since its publication (2022) has encountered surprisingly large interest from researchers. The details of the validation are described later in the work.

2.6. Physiological and Mental Correlates of Flow

In recent years, flow self-report studies have been accompanied by studies of the physiological and neural correlates of flow (Khoshnoud et al. 2020, Alameda et al. 2022). Alameda et al. studied publications dealing with the neural basis of the flow state. Based on the results of the selected 25 studies. On the one hand, studies using neuroimaging techniques during (attempts to) induce flow seem to converge on the key role of structures related to attention, executive functions and reward systems, assigning frontal brain areas a key role in the experience of flow. On the other hand, the dynamics of these brain areas during the flow state are inconsistent across studies, as illustrated vividly by their proposed summary (Table No. 1).

Table 1. Summary of studies relating to the dynamics of brain areas during the flow state

technique	publication	conclusions	
fMRI	Ulrich et al., 2014, 2016a, 2018		IFG and the medial prefrontal cortex
	Huskey, Craighead et al., 2018, Huskey, Wilcox et al., 2018	mixed patterns of activation and deactivation of specific frontal areas	DLPC
	Ju & Wallraven, 2019		default mode networks
fNIRS	de Sampaio Barros et al., 2018, Yoshida et al., 2014	increased prefrontal activity	

	Hirao, 2014	reduced prefrontal activity	
	Harmat et al., 2015	no significant changes in prefrontal activity	
EEG	Katahira et al., 2018, Knierim et al., 2018	in frontal locations, increased power of individual brain rhythms	theta
	Knierim et al., 2018, Núñez Castellar et al., 2019		alfa
tDCS	Gold & Ciorciari, 2019, Ulrich et al., 2018	the central role of the prefrontal cortex	

Various methodological approaches have been used to induce flow, such as: arithmetic tasks, video games, verbal fluency tests, mental imagination tasks, running a marathon or playing an instrument. Some approaches have focused on manipulating only one of these subcomponents of flow (e.g., balance of skill and difficulty, intrinsic reward).

Two theoretical models, **the transient hypofrontality hypothesis (THH)** and **the synchronization theory of flow (STF)**, which would explain the results of the above summary stand at radically different positions on the neural dynamics associated with flow state. The transient hypofrontality hypothesis (THH), supported by numerous studies (Gold & Ciorciari, 2019, Hirao, 2014, Katahira et al., 2018, Núñez Castellar et al., 2019, Ulrich et al., 2014, 2016a, 2016b, 2018, Wollseiffen et al., 2016, Yun et al, 2017) emphasizes suppression of frontal activity during the flow state, which would reduce interference with explicit processing (i.e., self-referential thinking) and facilitate implicit processing (i.e., automated processes). However, according to Alameda et al. (2022), even assuming that these studies did indeed capture the neuronal signatures of the flow state, their findings would suggest specific flow-related brain patterns rather than a general deactivation of frontal areas.

In contrast, the synchronization theory of flow (STF) is based on findings from neuroimaging studies of hypnosis and meditation, i.e., activities similar to flow but showing strong frontal brain activity (Newberg and Iversen, 2003). Newberg and Iversen points to increased neuronal synchronization between executive, alerting and orienting attention networks during the flow state. This approach would explain why flow is perceived as effortless, even though the tasks used to induce it require a minimally moderate to high level of difficulty (Huskey, Craighead, et al., 2018, Huskey, Wilcox, et al., 2018). These two theories attempt to reconcile the internal flow model proposed by Golda and Ciorciari (2021), indicating a role for cerebellar regions. Ulrich et al (2016a) observed activity in the cerebellum, premotor regions and precentral motor cortex during the flow state. Klasen et al (2012) found activity in the cerebellum and some regions of the reward system (e.g., putamen).

In sum, the evidence to date is inconclusive, but may provide a starting point for further research. Khoshnoud et al. (2020) point out the wide disparity in measurement methods and tools (FSS-2 being the most common), the varying decisions of researchers as to whether to measure global flow or its individual dimensions, and finally that based on existing methods it is difficult to distinguish between internal flow states and external conditions that help trigger the flow experience.

Other researchers point to the importance of the length of the measurement block (Bisson, Tobin & Grondin, 2012, Tobin, Bisson & Grondin, 2010, Yun et al., 2017) specifying a minimum of 25 minutes for the participant to have a chance to enter the flow state. A theme raised constantly is the issue of game selection. Games differ drastically in their requirements (e.g. Counter Strike vs. Star Craft II vs. Tetris), making it seem inadequate to juxtapose the results of studies of different games on such a sensitive and little-known area as flow.

Here, Alameda et al. (2022) first point out the need to change the type of tasks chosen to induce the flow state to the most engaging possible, i.e. video games or physical exercise. They go on to suggest studies on larger groups (of the studies included here, more than half N < 20) with experienced gamers, do represent women (in the study included by Alameda, 72.6% of the total sample was male), and follow the same participants in repeated measurements. An interesting indication is the value of using wearable systems to measure brain activity (such as the wearable Dry-EEG headset), which can help collect neural data in ecological situations where it is easier to evoke the experience of flow.

Khoshnoud et al. in a meta-analysis separated the distinct physiological and cognitive subfunctions involved in the experience of flow, and as a result concluded that flow is a positive mental state characterized by heightened arousal, focused attention, synchronized activity in the brain's attention and reward networks, and results in automatic control of actions, with less self-referential processing (Khoshnoud et al., 2020). Importantly, the authors pointed out the need to combine objective measurements of flow with retrospective questionnaires, which would have a chance of capturing the actual appearance of flow.

The pattern of a person's arousal modulation was found to be complex and varied depending on how studies used it to distinguish flow states from aggravating experiences, such as stress. Peifer and colleagues (2014) proposed an inverted U-shaped function between flow experience and physiological arousal.

A state of focused attention

Flow experience has been found to be associated with increased activity in the prefrontal cortex (PFC) (Klasen et al, 2012, Ulrich, Keller & Grön, 2016, Ulrich et al, 2014, Yoshida et al, 2014). The high theta activity noted during flow (Katahira et al, 2018, Metin et al, 2017, Nacke, Stellmach, & Lindley, 2011) may reflect focused attention, while Frontal-Midline-theta activation has been linked to concentration, working memory and sustained attention (Cavanagh & Frank, 2014). According to Khoshnoud et al (2020), the state of flow is accompanied by effortful attention and coupled sympathetic and parasympathetic nervous system activity, which can be used to distinguish flow from impaired mental experience.

Both flow and mental effort increase with increasing task difficulty (Tozman & Peifer, 2016). However, in the context of flow, engaged attention in action is understood to be effortless. The specific pattern of autonomic nervous system activity observed during flow (e.g., shortened heart rate period with deep breathing) differs from the pattern associated with mental effort (e.g., shortened heart rate period, lower heart rate variability (HRV), and rapid and shallow breathing). Studies that found lower HRV under flow conditions indicated greater mental effort during flow (De Sampaio Barros et al., 2018, Harris, Vine & Wilson, 2016, Keller et al., 2011). In contrast, studies that observed higher HRV suggested lower mental effort (Bian et al., 2016, Peifer et al., 2014). The reasons for the inconsistency in this case may be sought in the imprecise measures used to assess mental effort (Khoshnoud et al. 2020).

Attention and reward networks

Flow is considered an intrinsically rewarding state of focused attention. Some studies support the synchrony theory (Weber et al., 2009), showing joint activation of frontoparietal attention networks (e.g., IFG and inferior parietal lobe) and reward networks (e.g, putamen, thalamus) during the flow experience (Castellar et al, 2016, De Sampaio Barros et al, 2018, Huskey et al, 2018, Ju & Wallraven, 2019, Klasen et al, 2012, Ulrich, Keller, & Grön, 2016, Ulrich et al, 2014, Yoshida et al, 2014). A positive correlation has been shown between dopamine receptor availability in the striatum and putamen and the propensity to flow, supporting this theory and demonstrating that the experience of flow is intrinsically rewarding (De Manzano et al., 2013).

Automaticity

Research on the mechanisms underlying the experience of flow (Gold & Ciorciari, 2019, Ulrich, Keller & Grön, 2016, Ulrich et al, 2014) has highlighted the possible role of the theory of transient hypofrontality, a state in which the prefrontal cortex (PFC) of the brain experiences a temporary reduction in activity (Dietrich, 2004). This hypothesis received only partial confirmation - it was not confirmed by Harmat et al.(2015) or Yoshida et al. (2014). It may be an oversimplification and only apply to specific situations, such as occurring after prolonged practice, when the activity becomes more automatic (Harris, Vine & Wilson, 2017). And even during tasks with a high demand for executive control, disconnection of actions from conscious effort and controlled attention is unlikely.

Loss of self-awareness

The high concentration and focused attention required by a task limits the allocation of resources for task-irrelevant demands such as body and self-awareness (Sridharan, Levitin & Menon, 2008). Lower processing of self-referential information is associated with reduced neuronal activity in the amygdala during flow (Ulrich, Keller & Grön, 2016, Ulrich et al., 2014, Ulrich et al., 2018). Given the mediating role of the amygdala in emotion perception (Morris et al., 1996), reduced activity likely reflects reduced emotional arousal associated with the flow experience. Lower self-awareness may reduce the threat response and increase positive emotions (Sadlo, 2016, Ulrich, Keller & Grön, 2016). Reduced self-awareness also contributes to improved sports performance (Harris, Vine & Wilson, 2017). The close relationship between flow experience and performance (Engeser & Rheinberg, 2008, Jin, 2012, Landhäußer & Keller, 2012) suggests that reduced self-awareness is one of the primary key features of flow experience.

Flow emerges at the intersection of the mental and physiological. As our understanding of the neurophysiological underpinnings of flow deepens, two leading theories - the transient hypofrontality hypothesis (THH) and the synchronization theory of flow (STF) - continue to challenge and neither provides a fully conclusive picture. The evidence points to a complex orchestration of cognitive functions during flow, marked by heightened arousal, focused attention, synchronized activity across attention and reward networks, and automaticity of action. Furthermore, reduced self-referential processing and self-awareness appear to be a key feature of the flow state, contributing to the experience's intrinsically rewarding nature.

Flow vs. Personality

In the context of flow and personality, interesting results were presented by Heller et al. (2015) in a study of singers. They indicated that participants with high extraversion scores experience significantly more flow than less extroverted individuals, while less flow experience appears to be associated with high neuroticism scores. The longer the practice time, the more likely students are to achieve flow-experience. Confidence in operating an instrument is essential for inducing feelings of flow. However, flow-experience seems to be common mainly in amateur singers.

Ullén et al. (2011) found a negative correlation between flow propensity and neuroticism, and a positive relationship between flow propensity and conscientiousness. In particular, the hypothesis that flow propensity is negatively related to neuroticism was confirmed. The results related to neuroticism may be explained by the fact that neuroticism is characterized by a tendency to experience negative affect (Gray & McNaughton, 2000), which may interfere with the affective component of the flow state, i.e., pleasure (Csikszentmihalyi & Csikszentmihalyi, 1988, de Manzano et al., 2010). The instability of emotional (Eid & Diener, 1999) and cognitive states (Flehmig, Steinborn, Langner, & Westhoff, 2007), which is an important feature of neuroticism, is also manifested in the high variability of even simple behaviors, such as reaction time (Flehmig et al., 2007, Robinson & Tamir, 2005). Such fluctuations in performance can affect both cognitive and emotional aspects of flow, negatively impacting attention, reduced sense of control and skills. In addition, the relationship between neuroticism and flow propensity can be complex and mediated by other variables that affect an individual's propensity to participate in flow-friendly situations and activities. Komarraju, Karau, & Schmeck (2009) found that neuroticism is positively related to the motivation factor in Deci and Ryan's self-determination theory of motivation (Ryan & Deci, 2000), where it reflects a lack of motivation to engage in activities and a sense of aimlessness of involvement. Meanwhile, intrinsic joy (Hamilton et al., 1984) is positively related to flow propensity, as well as internal locus of control, which in turn is negatively related to neuroticism (Clarke, 2004).

Conscientiousness is positively related to flow propensity, as are other variables that also show a positive relationship with flow propensity, i.e. active coping (D'Zurilla et al., 2011), life satisfaction, subjective happiness and positive affect (Marrero Quevedo and Carballeira Abella, 2011), and intrinsic and extrinsic motivation (Komarraju et al., 2009). Moreover, individuals with high conscientiousness are likely more likely to devote enough time to deliberate practice to master more difficult tasks (Kappe & van der Flier, 2010), which on the one hand allows, even in a more difficult baseline, for skill -balance, and on the other hand may combine with time requirements of flow, e.g., no less than 25 minutes in a game so that there is a chance for flow to occur (Bisson, Tobin & Grondin, 2012, Tobin, Bisson & Grondin, 2010, Yun et al, 2017).

Flow vs. Intelligence

A study by Ullén et al. (2011) found no correlation between flow propensity and intelligence, concluding that flow propensity relies on different mechanisms than those involved in attention during mental effort.

3. Video Games as a Research Environment

3.1. Flow in Video Games

A person experiencing flow is focused, present in the “here and now”. Understanding the specifics of flow, related to functional characteristics (including motivation, sense of focus, confidence), can be part of the answer to how to manage one's own performance more effectively (Harris et al. 2021, Landhäußer & Keller, 2012). In the context of performance, flow has most often been studied in sports (Swann et al., 2016, 2017, Jackson & Kimiecik, 2008, Sinnamon et al., 2012) and in the context of video games (Nah et al., 2014, Engeser & Rheinberg, 2008, Keller & Blomann, 2008, Campbell et al, 2018, Pedraza-Ramirez et al, 2020, Gao & Lu, 2021, Gutierrez, 2021, Cai et al, 2022, Jogo et al, 2022, etc.) and gamification, that is, the application of game mechanics to non-game areas (Wang et al, 2009, Procci et al, 2012, Hamari & Koivisto, 2014). Games, due to the complexity of the activities, provide a kind of flow base. The player is in a positive mental state, so focused on the game that nothing else matters. Like sports, the most commonly chosen environment for studying flow, they naturally meet its proximate conditions: clear goals, immediate feedback, and a balance between challenge and skill (Kawabata & Mallett, 2011). Despite the differences in terms of the level of physical exertion and associated psychological effects - there is considerable overlap between skills in sports and video games in terms of perceptual, attentional, motor and decision-making abilities, which understate performance in both (Jenny et al., 2017, van Hilvoorde & Pot, 2016). Both sports and games can be described as highly skilled visuomotor tasks that require the integration of visual input with motor output. (Campbell et al., 2018, Pedraza-Ramirez et al., 2020). With the development of e-sports, the line between the two is becoming increasingly blurred (Holt, 2016, Jenny et al., 2017). In addition, both sports and games provide objective performance measures that enable quantification of flow relationships, are highly absorbing (Kiili et al., 2012, Michailidis et al., 2018), but also allow for experimental control of challenges. The approach of manipulating game requirements to provide tasks that are too easy, too difficult and optimally challenging is a common method of manipulating flow in game research (Baumann et al, 2016, Engeser and Rheinberg, 2008, Harris et al, 2019, Keller and Bless, 2008, Keller and Blomann, 2008). Research on video games offers hope for transfer, where the flow-performance relationship can apply to domains other than those based on physical exertion (Harris et al. 2021). Sports are available to everyone, but the effort required to engage in them is sometimes disproportionate to the reward, which is too high an entry threshold for many people. And we're talking about physical effort, as well as the time and logistical support of others (e.g., the desirable involvement of at least one parent, if only to drive children to activities). Meanwhile - often for the same people - the game, implemented from the moment the computer is turned on, and limited by the possession of sufficient equipment and the time a person can spend in the game, rewards disproportionately to the effort. The mechanics and reward systems that are an immanent part of games, constructed and composed based on experience so as to keep the player in the game for as long as possible, i.e. success thresholds difficult enough to interest, yet easy enough not to discourage. As a result, the game is an entity that can quickly capture the player. Researchers - from psychologists to economists - are interested in trying to find answers in the game-player relationship to questions about this quality of engagement also in domains distant from games, such as work or leisure. Current research on games in the context of flow focuses in particular on 3 thematic areas: flow theory per se (Cowley et al., 2008, Su et al., 2016), addiction (Young 2017, Kuss 2013, Wu, Scott and Yang 2013), and gamification, i.e. the application of game elements in non-game contexts (Deterding et al., 2011, Acland 2020). Regardless of the specific area of research, existing knowledge about the sources of flow and its effects, including the flow-performance relationship, does not provide clarity on either the strength, manner or causal direction of the processes involved in the flow relationships (Moran & Toner, 2017, Swann et al., 2018).

Researchers look at the context in which the flow state occurs. Consideration is given to the importance of the identity of the place where the activity is performed (Bonaiuto 2016), the presence of rewards or punishments, as well as the level of performance (activity history), the perception of the passage of time or (here specific to games) identification with the character. The specific context here is the player himself and the answer to the question of how his personality, cognitive functions, behaviors, emotions or, finally, susceptibility to flow can correlate with the flow state resulting from the task. In the context of video games, an important element is how the player's flow can be influenced by the game's intelligence, adjusting the level of challenge to the player's skill, such as through tools like Dynamic Difficulty Adjustment (DDA). There is also the question (Bonaiuto 2016) of how much a player's flow is affected by the presence of another player performing the same task (Labonte-Lemoyene 2016). Weibel et al (2011) found that a human-controlled opponent generates more flow experiences than a computer-controlled opponent. Moreover, flow mediates the relationship between presence and pleasure (Pertula 2017).

3.2. Areas Explored in the Video Games Environment

In 2014 Fui-Hoon Nah defined nine major research directions related to the player's flow: games in learning and education, presence, adoption, addiction, neural correlates of flow, flow measurement, e-marketing, interactivity and nomological network for flow. Some of them deal exclusively with games, some with games and players, and some with player functioning. In the latter group, the most widely explored areas are:

- **cognitive functions** (cognitive control, ability to switch between changing tasks, refreshing information in short-term memory (Colzato et al., 2013, Koala et al, 2018), hand-eye coordination (Barlett et al. 2009, 2009, Griffith et al., 1983), visual-spatial orientation (Green and Bavelier, 2003, West et al. 2008), selective visual attention, executive functions (Bavelier et al. 2012, Castel et al. 2005, Green and Bavelier, 2003),
- **addictions** (Pawlowska et al. 2018, Stockdale, Coyne 2018, Bean, Nielsen 2017, Plante et al. 2019),
- **personality** (Braun et al,. 2015, Bean et al,. 2016, H.-C. Huang et al,. 2018, Laier et al, 2018, Matuszewski, Dobrowolski 2019, Zammitto 2010, Peever et al. 2012, Borders, 2012),

- **education** - developing strategic thinking, problem solving, planning, adaptation to changing contexts and flexibility (Fabricatore 2020, de Freitas, Sara 2006, Gee 2003, Gopher et al. 1994),
- **relationships** (Galuszka 2019),
- **physical health** (Mentzoni et al. 2011, Rogalewicz , 2018),
- **mental health** (Wenge Xu et al. 2020, Jagadheeswari et al. 2018).
- **motivation, engagement and flow** (Graham et al., 2013, Shao-Kang et al., 2017, Silva 2016, Cruz, Uresti 2017, Johnson 2014).

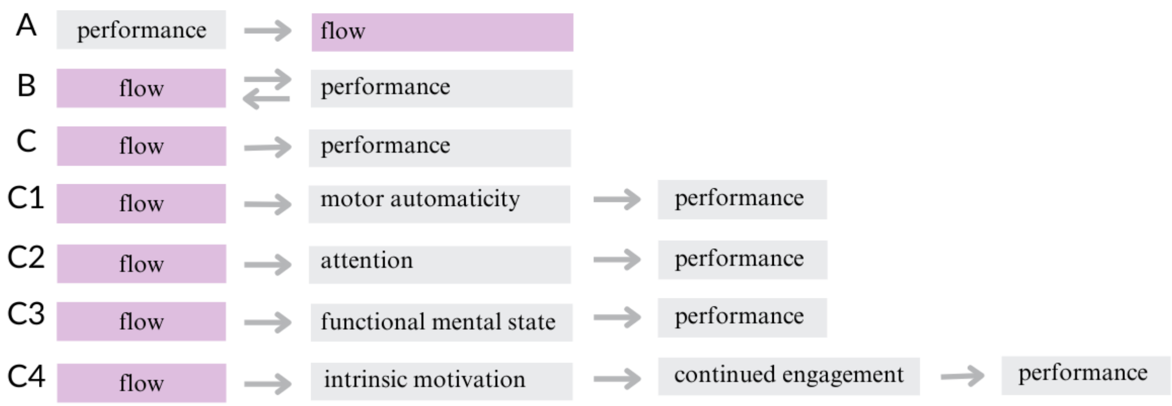


Figure 3. Flow-performance relationship diagram and proposed mechanisms from the systematic review. (after Harris et al. 2021) None of the studies focused directly on relationship a or b, but both were considered as possible relationships (Jin, 2012; Schattke et al., 2014). Relationship c was the most common and discussed explicitly in at least 11 articles c.1 (Koehn et al., 2013), c.2 (Harris et al., 2017, 2019), c.3 (Engeser & Rheinberg 2008, Sklett et al., 2018), c.4 (Schüler and Brunner, 2009). Regarding the two pathways for increasing performance proposed by Landhäußer and Keller (2012), c.1, c.2 and c.3 refer to the direct pathway, and c.4 to the indirect effect of motivation.

3.3. Challenges Faced by Researchers in the Video Game Environment

A compilation of key studies on flow and video games in the context of performance (after Harris 2019) (Tab. 2) highlights not only the interest in the topic, but also the challenges researchers face. For the purposes of this dissertation, six basic challenges were distinguished, which are related to the wealth of options provided by the game environment. The clue here is the lack of uniform standards in terms of: **type of games, concept of player,**

measurement tools, size of study groups, paradigms (players vs. non-gamers, dynamics of player cognitive functions during game training), **player characteristics based on self-report**. Each of these asperities is briefly discussed below.

Firstly, the **diversity of games**, significantly hindering their aggregate analysis and comparison of results. And it's not just the variety of titles, but the types of games that pose extremely different cognitive or motivational challenges to the player.

Table 2. Six genres of VGs (after Choi et al., 2020)

Genres	Sub-genres	Explanation
TG - traditional games		VGs that have been played in other mediums for a relatively long time, puzzles, card games and board games etc.
SG - simulation games		VG that are played to do relatively daily activities or that are played based on players' imagination for things that are difficult to be realized in real world, sports games or driving VGs, Sims etc.
SVG - strategic video games	real time strategies RTS	VGs where players take an active role in making the desired result by engaging relevant thinking process in VG playing thinking the strategies by themselves
TBS - turn-based strategy		type of strategy game in which you take turns to make a move, checkers and chess, for example: Darkest Dungeon, Total War i Civilization.
AVG - action games	first-person shooters FPS	VG played in the perspective of players
	third-person games TPG	VGs played by using the avatars whose experience relies on the arrangement of space and time in game environments
FG - fantasy games	RPG	VGs where players take the active control over avatars in the exploration of the environment, completion of quests and competing/ battling with enemies
	adventure games	VGs hat players explore and investigate the VG environment in slow pace by focusing on problem solving (Apperley, 2006)

In addition to the above division, it is important to distinguish the option of Massive Multiplayer Online RPGs (MMORPGs), i.e. games in which the social and participatory aspect is crucial (Apperley, 2006, Pinelle et al., 2008).

In the process of categorizing video games, aspects other than those considered by Choi (2020) may be relevant, such as the type of interactions that players experience in video game environments (Pinelle et al. 2008), which, de facto, may be relevant to research on the relationship between VGs and the dynamics of changes in cognitive functions. VGs can be classified as different genres depending on the aspect the researcher focused on, for example, RPGs, categorized as "FG" based on the characteristics of the video game environment (Pinelle et al. 2008), were categorized as "SVG" based on how players acted in video games (Adachi & Willoughby 2013). Moreover, specific games are being expanded and developed in ways that prompt them to be reclassified. Second and third is the **variation in measurement tools** and the **discrepancy in study group sizes** - depending on the complexity of the study.

Table 3. Summary of key studies on flow and video games in the context of performance (after: Harris 2019)

Authors	Baumann et al.	**Year of publication**	2016
N (male/female)	93 students (34/59)	**Measure**	Flow Short Scale
Design and procedures	Completed FSS and ratings of enjoyment after three skill-demand balance conditions of computer game	**Activity/ Performance metric**	Adaptive sidescroller game („Sideway runner")/ game points
Key findings	Flow was greater when skill-demand balance was dynamic and was significantly correlated with game performance. Enjoyment dissociated from flow at higher levels of challenge.		
Authors	Chen and Sun	**Year of publication**	2016
N (male/female)	260 students (110/156)	**Measure**	Modified flow state scale (from Pearce et al., 2005)
Design and procedures	Completed FSS and ratings of enjoyment after three skill-demand balance conditions of computer game	**Activity/ Performance metric**	computer game („Music flow")/ game points

Key findings	Found a positive relationship between self regulation ability and in-game flow.		
Authors	Cowley et al.	**Year of publication**	2019
N (male/female)	9 students (6/3)	**Measure**	Flow Short Scale
Design and procedures	Participants played the game then completed the flow scale (40 items) across eight occasions	**Activity/ Performance metric**	adaptive driving game ("CogCatSim")/ game points from driving speed and obstacle collisions
Key findings	Flow was high regardless of trial number or skill development. Instead flow fluctuated in line with trials that were particularly good/bad.		
Authors	Engeser and Rheinberg	**Year of publication**	2008
N (male/female)	60 (12/48)	**Measure**	Flow Short Scale
Design and procedures	Completed flow scale after each round of Pac-Man at three levels of difficulty.	**Activity/ Performance metric**	computer game ("Pac-Man")/ game points
Key findings	Perceived balanced challenge and skill had a quadratic relationship with flow. Proposed direction: flow > performance (better functional state and higher motivation).		
Authors	Harris et al.	**Year of publication**	2019
N (male/female)	33 (17/16)	**Measure**	Flow Short Scale
Design and procedures	Completed flow scale after driving with internal or external focus instructions.	**Activity/ Performance metric**	simulated driving/ race completion time
Key findings	External focus of attention induced significantly higher flow experience but had no effect on performance. Flow was positively related to performance. Proposed direction: flow > performance (attentional mechanism).		
Authors	Jin	**Year of publication**	2012
N (male/female)	115	**Measure**	Composite measure using items taken from existing flow scales
Design and procedures	Completed flow measure after playing either shooting or	**Activity/ Performance metric**	shooting game ("Call of Duty") or medical simulation game

	medical simulation game.		(“Trauma Center”)/ game points
Key findings	Flow ratings were significantly higher in participants who succeeded in the game versus those who failed. A feeling of competence was positive predictor of flow.		
Authors	Keller and Bless	**Year of publication**	2008
N (male/female)	72 students (28/44) & 149 students (64/85)	**Measure**	14-item involvement and enjoyment scale
Design and procedures	Completed scale after three game conditions (boredom, flow, overload).	**Activity/ Performance metric**	computer game (“Tetris”)/ number of completed lines
Key findings	Performance did not significantly predict flow. Participants in the flow condition reported more enjoyment and time passing more quickly. Proposed direction: flow > performance.		
Authors	Keller and Bloomann	**Year of publication**	2008
N (male/female)	122 (56/66)	**Measure**	16-item involvement and enjoyment scale
Design and procedures	Completed scale after three game conditions (boredom, flow, overload).	**Activity/ Performance metric**	computer game (“Tetris”)/ number of completed lines
Key findings	No significant relationship between flow and performance. Flow was more closely related to optimal challenge than performing well. Participants with an internal locus of control experienced greater flow.		
Authors	Schmidt et al.	**Year of publication**	2020
N (male/female)	23 (19/4)	**Measure**	Flow Short Scale
Design and procedures	Participants completed flow scale and had cortisol measured after competitive esports games.	**Activity/ Performance metric**	computer game (“League of Legends” and “Counter Strike”)/ game success (win/ loss)
Key findings	Game winners reported higher levels of anxiety, compared to losers, but no difference in flow.		

As can be seen in the above overview (Table 3), self-report questionnaire methods (Flow State Scale-2 (FSS-2) and Dispositional Flow Scale-2 (DFS-2) are still the most popular in the context of games. However, Procci et al. found that improvements are needed to the DFS-2 scale in the context of games. Brockmyer et al. (2009) developed the Game Engagement Questionnaire (GEQ), which includes a subscale for flow, as well as subscales for presence, absorption and immersion. Still another approach was proposed by Sweetser and Wyeth, who constructed the GameFlow model for assessing game enjoyment. The GameFlow model consists of the elements of focus, challenge, skill, control, clear goals, feedback, immersion and social interaction, each of which contains a set of criteria for achieving game enjoyment (Pertula, 2017). Kiili et al. (2005) proposed an experiential game model that is based on experiential learning theory, flow theory and game design. In Kiili's model, flow theory is used as a framework to facilitate positive user experiences to maximize the impact of educational games. In addition, Kiili proposed a flow framework for educational games to facilitate the analysis of educational games and provide design support for game developers (Pertula, 2017). Hsu and Lu (2004) used a technology acceptance model that includes social influence and flow experience as a theoretical constructs, to predict people's acceptance of online games. Flow experience was identified as one of the main predictors of intention to play online games in the future. In addition, good usability of the game interface was found to be a critical feature of the flow experience (Pertula, 2017).

Fourth, there is no consistent **definition of a player**, which significantly limits the ability to generalize conclusions. There have been more studies focusing on action video games (AVGs) than on other video game (VG) genres, and the criteria for player status varied between studies. While non-video game (VG) gamers were mostly defined as individuals with little or no experience, action video game (AVG) gamers were classified as non-VG gamers in some studies. The different classification criteria appear to underestimate the potential impact of non-action video games on cognitive function and make comparisons between studies difficult.

Fifth is the challenge of two **different paradigms, looking at gamers and non-gamers and focusing on the dynamics of a player's cognitive functionning during game training**. Some researchers combine the two situations. Each of these directions has its own specific potential to support looking at the player, while at the same time there are impediments in the essence of these approaches. Thus, in the case of research on players and non-gamers, differences in learning and decision-making are observed. Non-players are theoretically observed in a "pure form" untainted by the game when starting the study. Even here, challenges can arise. Given the shrinking population of people researchers have access to who have never played video games, studies are increasingly admitting as non-gamers people who have had little experience and/or have had experience in a type of game other than the one proposed in the study (e.g., less than 5h in RTS and FPS and MOBA, or experience with games only in the last 6 months). And finally - sixth - player characterization based on **self-reporting**. Since self-reporting is based on self-awareness and autobiographical memory, this can result in inaccurate reporting of common behaviors. It is worth noting here that candidate declarations for the project, whether motivated by the desire to participate or to get paid, lead to false information, e.g.: experience/no experience in gaming, frequency of previous gaming, types of games. If the study includes a training component for the entire duration of the study, the subject should only play as part of the training. Here, too, false information can be encountered, e.g., non-gamers participating in training play "after hours," study at home, or use boosters in the form of tutorials or downloads during training sessions. In the case of the gamer study, the challenges are particularly related to habits, i.e. individualized keyboard and other customizations, the lack of which, resulting from the universalization of the study conditions, interferes with optimal performance.

3.4. Video Games - Cognitive Treasure Trove. Rather a Labyrinth…

3.4.1. The impact of video games on cognitive functionning

The growth of the game market has entailed the development of fields for which video games provide an attractive research environment. They provide players with a rich environment of cognitive, emotional and social experiences, enhancing their cognitive functions by simulating cognitive processes in the process of performing tasks required to succesfully play video games (Röhlcke et al., 2018, Nuyens et al., 2019).

In the context of cognitive functioning, positive effects of intensive gaming are observed on: executive control (Strobach et al. 2012, Oei and Patterson 2013), or attentional control (Chisholm and Kingstone 2012, Green and Bavelier 2012, Nuyens et al., 2019), as well as the ability to switch between changing demands or rules (Colzato 2010, Green et al. 2012). Positive effects of games on working memory functioning have also been reported (Blacker and Curby 2013, Colzato et al. 2013, Wilms et al. 2013), as well as more effective inhibition of distracting stimuli (Mishra et al. 2011), more effective filtering of distracting information in a paradigm measuring the distribution of visual attention (Bavelier et al. 2012). In addition, according to studies, gamers show increased concentration (Green and

Bavelier 2003, 2006, Feng et al. 2007), are more effective at simultaneously tracking multiple objects (Green and Bavelier 2006, Sungur and Boduroglu 2012), search the visual field (Castel et al. 2005), and better detect significant changes in the direction of object movement (West et al. 2008). It has been suggested that video games can also delay cognitive decline (Griffiths et al., 2013). A different set of information is brought by studies using violent video games, where negative effects on executive functions have been reported (Bailey, West and Anderson 2010, Wang et al. 2009).

3.4.2. Cognitive training with video games

Clearly, such intense potential of video games has been seen as another hope for the - still insufficiently satisfying (Sala et al., 2019, Sandra Luis-Ruiz et al., 2020, Westwood et al., 2023,) - cognitive training interventions, i.e., planned targeted activities aimed at influencing and improving cognitive functions and/or verifying what their development or lack of development depends on. Researchers are looking at cognitive functions in a variety of contexts, ranging from life success (Strenze, 2007, Watkins et al., 2007, Lynn, Yadav, 2015) to intelligence resources, which in people who train systematically, such as chess players (Burgoyne et al., 2016, Sala et al., 2017) and musicians (Schellenberg, 2011, Swaminathan et al., 2017) show higher scores than non-trainers.

Studies using VGs of various genres have highlighted the overall cognitive, perceptual and emotional benefits of training interventions (Wang et al., 2016, Pallavicini et al., 2018). Training using complex video games has been found to affect memory, multitasking, spatial rotation, processing speed and even emotional skills (Pallavicini et al., 2018) and generally changes the human brain, both its structure and activity (Palaus et al., 2017, Brilliant et al., 2019 etc.). Therefore, such training can strengthen the neural scaffolding (Park & Reuter-Lorenz, 2009). However, some results reported in the literature contradict this positive picture (Boot et al., 2008, van Ravenzwaaij et al., 2014).

Demonstrating a causal relationship between task performance and increased cognitive abilities is challenging. While some studies have found that training domain-specific skills related to specific tasks improves task performance itself, there appears to be no transfer to the overall, domain-general cognitive abilities. Both chess and music training (Gliga & Flesner, 2014, Sala & Gobet, 2017) do not show benefits to cognitive ability in training studies, especially when an active control group is used as a baseline. Answers to this problem have been sought without much success in direct ability training

(Taatgen, 2016), such as attempts to improve fluid intelligence by training working memory as its strong correlate (Conway et al., 2003, Jaeggi et al., 2008, Chuderski, 2013). Meanwhile, an opportunity to benefit training (Sala & Gobet, 2019), despite methodological concerns (Boot et al., 2011, Unsworth et al., 2015, Sala et al., 2018), has been shown to be training with the use of video games.

Meta-analytic data indicate that video game players outperform non-video game players on a wide range of cognitive tasks at average effect sizes (Powers et al, 2013, Powers & Brooks, 2014, Bediou et al, 2018, Sala et al, 2018, Green & Bavelier, 2015). In a number of studies (Powers et al, 2013, Powers & Brooks, 2014, Wang et al, 2016, Bediou et al., 2018), NVGP training using video games results in small to medium effect sizes for improving cognition in all cognition domains considered, although Bediou et al (2018) note that the benefits are mixed. The largest effect sizes were in the domains of spatial cognition (mental rotation, spatial working memory etc.), top-down attention (complex search, multiple object tracking) and perception (contrast sensitivity, lateral masking etc.). These effects persist even when considering only training studies that used an active control group (Bediou et al., 2018), which provides a higher standard of evidence than the usual passive control groups. Unfortunately, correcting for modeling errors and publication bias (Sala et al., 2018) indicates that the true impact of video game training on overall cognitive ability might be lower than claimed.

3.4.3. Cognitive functions vs video game genres

Action games, which traditionally include first-person shooter (FPS) and third-person shooter (TPS), have been considered particularly valuable in the context of cognitive function development. Their peculiarities were described by Bediou (2018) and Green & Bavelier (2015) indicating that they typically contain features considered crucial for influencing cognition, such as a fast pace, a high degree of perceptual and motor load, working memory, planning and goal-setting, an emphasis on constantly switching between a highly focused state of attention and a more distracted state of attention, a high degree of clutter and distraction.

Meanwhile, the conditions described above are met by yet another game genre: real-time strategy (RTS), which was not originally included in the action game group, or its players were treated as NVGPs, so it has a not very rich body of evidence in the cognitive enhancement context (Dobrowolski et al, 2015, Dale & Green, 2017, Klaffehn et al, 2018, Boot et al. 2008, Glass et al. 2013). Unlike FPSs (first-person perspective) and TPSs, RTSs are played from an up-bottom perspective, i.e., as in chess, players are given control over a set of specialized units that they must deploy on a board (map) in order to defeat their opponent. A study comparing the FPS and RTS found that players of RTS games have better multi-object tracking skills and faster processing speed (Dobrowolski et al., 2015). RTS games promote cognitive flexibility, switching between multiple activities and maintaining sustained attention (Glass et al., 2013, Vinyals et al., 2019). Players simultaneously create units, manage resources, (Dobrowolski et al., 2015), and make decisions in real time (Vinyals et al., 2019, Dobrowolski et al., 2015, Kim et al., 2015).

According to another classification, video games are standardly divided into two genres depending on the purpose of development: serious games, developed to learn and change behavior in various fields such as business, education, healthcare and government policy (Connolly et al. 2012, Zyda 2005), and commercial VG games, designed to entertain players (Pinelle 2008, Song et al. 2013). Interestingly, it has been found that gamers develop their cognitive skills in a more integrated way when playing commercial games (Baniqued 2014), for which, *de facto,* they are more motivated (Oei 2014).

3.4.4. Gamers vs. Non-gamers. The Importance of Experience in Video Games

Whether a person has experience with video games turns out to have a far greater than intuitive impact on how he or she behaves in the game, and thus how he or she engages his or her cognitive functions in the game. Looking at inconsistent results from studies of individual differences between subjects (Bavelier et al., 2011), Macnamara et al. (2014) estimated that 26% of the variability in VG scores is a result of game practice, while the rest is accounted for by the effect of predisposition on neuroanatomical and cognitive performance, as well as by demographic characteristics. The researchers compared expert players with those without VG experience and suggested that either the extensive training that experts undergo or underlying individual differences (the "self-selection effect") may lead professional players to perform better on a variety of cognitive tasks (Boot et al., 2008). Beginner gamers are more likely to use top-down processes, in which attentional resources were allocated through strategic control of in-game behavior, while video game experts, as a result of experience, are more likely to use bottom-up processes, in which attention is automatically allocated to psychologically relevant in-game cues (Zhang et al., 2017). For example, in League of Legends (LoL), higher-ranked players prioritized strategic skills, while lower-ranked players focused on strictly action-related skills (Gong et al., 2019). At the same time, in the first-person shooter (FPS) context, although the papering of cognitive functions was lower in those with less experience, limiting the playing of video games significantly reduced not only the sense of gaming skills, but also brain activity (Unsworth et al. 2015, Gong et al., 2019). This was considered a rationale for concluding that VG experiences have the potential to enhance cognitive function and demonstrate a near-transfer effect, as a certain amount of video game experience is required to demonstrate cognitive enhancement (Anguera et al. 2015).

3.4.5. Factors Modulating Cognitive Performance

A positive relationship has been shown between playing video games and cognitive functioning. However, there is individual variation in the degree to which players show cognitive reinforcement (Wu et al., 2012), which is due to the influence of specific factors on plasticity and individual responses to video game training (Oel, Patterson, 2014). In addition to game experience, 4 more factors have been identified that modulate the relationship between playing video games and cognitive reinforcement: age, baseline cognitive functioning, gender, and motivation. In this study, two additional factors were examined - personality and intelligence. Personality, because according to researchers, it has a relationship with gaming (Gray & McNaughton, 2000; Khan et al., 2016; Matuszewski et al., 2020), and intelligence, because judging by the abundance of research in this area (Ullén et al., 2011, Sharma et al. 2021), it is considered an untapped potential of influence.

Age

The effect of video games has a potentially greater effect on cognitive enhancement in younger adults than in older adults (Wang et al., 2016), which is sometimes associated with the less time older adults spend playing (Wang et al., 2016). Younger adults made significantly greater gains in overall cognition and processing/attention speed compared to older adults (Wang et al., 2016). Age also influenced engagement in video game training, which is combined with the specificity of the young adult population (Bediou et al., 2018) considered in game design. Interestingly, older adults showed less engagement in action video game (AVG) training compared to training of other video game genres (Boot et al., 2013). Age-related decline in cognitive control was found in older children (Bediou et al. 2018, Anguera et al., 2013). It has also been found that task performance in younger children with relatively slow and less precise attention processes becomes better when their performance is aided by providing temporal cues for attentional responses (Dye et al., 2009).

Gender

To date, there is no clear answer to the question of the relationship between a player's gender and the dynamics of changes in his or her cognitive functions (Dye et al., 2009). While men have been found to be better at inhibiting distractors and sustaining attention (Huang et al., 2017), ultimately the differences appear to be a factor heavily influenced by lifestyle. Gender influences frequency of play (Huang et al., 2017, Dindar, 2018), longer duration of play in men (Greenberg et al., 2010, Dindar, 2018, Ogletree, Drake, 2007), type of game (Billieux et al., 2013), and style of play - men preferred action games (Huang et al., 2017). As a gaming platform, men were more likely to choose the computer, which was related to motivation (e.g., social interaction). While men prefer to play competitive video games (e.g., AVG or SG), women prefer to play triadic games (Greenberg, 2010). In sum, gender indirectly - through game engagement habits - modulates the relationship between playing video games and improving cognitive function.

Player motivation

Studies of player motivation consider its various aspects, i.e., purpose (e.g., social , developmental, achievement-seeking, immersion in an alternate reality), frequency of game play and length of play (Allahverdipour, Bazargan, Farhadinasab, & Moeini, 2010), motivation for loyalty to the title (Teng 2010), immersion in the game itself (Williams et al. 2008), personality factors, including sources of stress, associated with excessive gaming (Leones do Couto & Cruz, 2014, Rehbein & Baier 2013), or treating gaming as a source of acceptance and self-esteem building (King & Delfabbro 2016). Individuals motivated to play by a desire to succeed showed an overall positive impact of play, while those motivated by a desire to immerse themselves in the game showed greater loneliness (Shen and Williams 2011). Cole and Griffiths (2007) showed that players interested in the social aspects of the game spent more time playing, and Williams and colleagues (Williams et al., 2008) that sociability is a key motivation and those who play with others are willing to play longer than those who play alone. Those with higher levels of motivation engaged in practice more voluntarily, performed better and showed improved working memory than those with lower levels of motivation (Prins et al., 2011). Gamers who experienced more fun and relatively less frustration while playing were more motivated to engage and showed more functional changes in relevant brain regions (Gleich et al., 2017). When a monetary reward was given for playing games, the effectiveness of training was not found to change (Baniqued et al., 2014, Zhang et al., 2017). According to self-determination theory, games satisfy people's universal needs for a sense of competence (a need for challenge and a sense of efficacy), autonomy (a sense of will and voluntariness), and connection with others.

Research has shown that satisfaction of basic psychological needs is associated with players' willingness to continue playing (e.g., Ryan et al., 2006), which in turn have a strong impact on motivation and a positive effect on the development of more intrinsically regulated motivation (Ryan and Deci, 2000a, b). Satisfaction of basic psychological needs may provide an explanation for why people play video games in the first place - gameplay increases enjoyment and thus provides satisfaction of their basic psychological needs (Ryan et al, 2006, Przybylski et al, 2009, Tamborini et al, 2010, Rogers, 2017). Potentially, this satisfaction also predicts how likely the player is to continue playing in the future (Ryan et al., 2006). However, different types of video games satisfy different basic psychological needs.

Playing time

Research on player motivation (Allahverdipour et al. 2010, Durkin and Barber 2002, Przybylski 2014, Shen and Williams 2011) shows that motivation differentiates players and can have a significant non-obvious impact on game evaluation. An example is the game time index. They found that the effect of time spent playing on various performance measures was significantly smaller than the effect of various demographic and personality variables. At the same time, there is a positive correlation between the number of hours spent playing and the number of friends in the game (Yee 2006). 60% of the time spent playing is explained by personality factors, including sources of stress and interest in others (Leones do Couto & Cruz, 2014). In sum, research on the impact of amount of gaming suggests that there may be a curvilinear relationship between hours of gaming and well-being-related outcomes: no gaming and very high levels of gaming are often associated with negative outcomes, while moderate levels of gaming are associated with relatively more positive outcomes (Johnson 2014).

In the video game literature, amount of play has most often been treated as an independent variable. This means that most of the existing research analyzes the effect of amount of play on the player and their well-being. In contrast, fewer studies have focused on the amount of play as the dependent variable, examining the factors that influence the amount of time spent playing. The current research attempts to address this imbalance by focusing on the latter. Previous studies have identified specific characteristics underlying gaming motivation (Vorderer, 2000, Vorderer et al, 2003, Sherry et al, 2006, Yee, 2006a, b, Greenberg et al, 2010, Demetrovics et al, 2011). For example, Vorderer (2000) and Vorderer et al. (2003) argue that interactivity and competition are two of these characteristics, with the former being related to communication and cooperation, and the latter being related to the ability to compare oneself with other players. Another study found that for college students, challenge, diversion and competition were the strongest types of motivation (Greenberg et al., 2010).

Röhlcke et al (2018) examined the predictive ability of several factors (i.e., number of games played, working memory capacity, grit, fluid intelligence, age and education). The study found that the number of matches played was the strongest predictor of performance, but there was no effect of cognition, which contradicts other findings (e.g. Nuyens et al., 2019).

The need to strive for mastery and challenge, was a significant predictor of performance. This is consistent with the results of Rogers et al. (2017), who recently suggested that games with flexible rules increase feelings of competence, and have previously been linked to performance within traditional sports such as soccer (Fransen et al., 2018). In this study, we found a similar pattern, which suggests that a sense of competence is a factor that can contribute to player performance. So, again in the context of video games, it seems reasonable to suggest that strategies that promote competence are something to strive for to promote performance.

There are, of course, several other possible explanations for the irrelevant effects of intrinsic motivation. Players may have clear motives for playing video games, such as increasing skill development or experiencing various social aspects of the game (Demetrovics et al, 2011, Hamari et al, 2015, Wu et al, 2016). It is also possible that these results reflect subconscious selection effects. Some players may choose games that match their personality traits (Graham and Gosling, 2013) and meet their needs in different ways, while some games emphasize social elements, which can lead to feelings of relatedness (Johnson and Gardner, 2010, Rogers, 2017). Socialization factors were a significantly greater motivator for female video game players than for men (Sun, 2017). Previous research has shown that although intrinsic motivation is considered an aspect that stimulates creativity, it does not work in isolation, but only in conjunction with certain personality traits (i.e., openness, Prabhu et al., 2008, Agnoli et al., 2015, 2018).

Player & Non-Player Personality

While there are numerous examples in the literature of research on player personality and studies centered around personality and flow, there are no studies showing how personality is related to flow in non-players during game training. What follows is a general insight into the research on player personality, followed by the results of studies considering the non-player population.

It is interesting to see the context in which researchers are looking at the personality of video gamers. The personality traits of gamers seem to influence motivation to play video games and motivation while playing (Granic, Lobel, 2014, Bryant, 2006, Graham, Gosling, 2013). E-sports, which naturally positions video gamers among athletes, is taking an increasingly strong position here, so it leads researchers to look for contextual knowledge about gamers in various physical sports. On the one hand, numerous studies indicate that participation (Kirkcaldy, 1985, Kirkcaldy & Furnham, 1991) and performance (Kirkcaldy, 1982, Kerr & Cox, 1991, Egloff & Gruhn, 1996, Khan et al, 2016) can go hand in hand with high extraversion (Amichai-Hamburger & Ben-Artzi, 2000, Tel & Sargent, 2004, Teng, 2013), with game genre having an impact. Users who preferred action games were characterized by the highest extroversion (Chory & Goodboy 2011, Braun 2008). On the other hand, that conscientiousness can be considered an important predictor of success in traditional sports (Mirzaei et al., 2013), high conscientiousness combined with low neuroticism (Piedmont et al., 1999), participation in competitions (Allen & Laborde, 2014), high conscientiousness and agreeableness, with (again) low neuroticism (Allen et al., 2011, Steca et al., 2018). Low conscientiousness was shown by role players (Graham & Gosling, 2014) and game addicts (Teng, 2008). However, no correlation was found between conscientiousness and the use of violent video games (Chory & Goodboy, 2011), which correlated with low agreeableness (Chory & Goodboy, 2011). Low agreeableness was also found in role-players (Graham & Gosling, 2013, Teng 2008).

At the same time, individuals with higher levels of neuroticism are more prone to mind wandering, such as positive constructive daydreaming, guilt, fear of failure, and poor attentional control (McMillan, Kaufmann & Singer) than those with lower levels of neuroticism (Robison et al., 2017) and tend to choose less adaptive coping strategies (Allen et al., 2011, Kaiseler et al., 2012). Given that emotional stability is generally beneficial to player performance in sports (Raglin, 2001) and in non-sports games such as poker (Laakasuo et al., 2014), it may also be important in the context of video games.

Video games are characterized by great diversity. Their unique mechanics - as in traditional sports - can appeal to different types of people, as indicated by the correlations between personality traits and video game preferences (Zammitto, 2010, Borders, 2012, Peever et al., 2012). Preferences may include aspects such as individual/team, entertainment/sport, leisure/challenge, storyline/no storyline, opponent is human/ AI, focus on rewards/ focus on development, among others.

For professional players or people for whom results are important, the game requires mastery and body control that avoids disruptive effects, such as when controlling a mouse (Witkowski, 2012). Individuals who engage in team games showed higher scores on the agreeableness dimension (Nia and Besharat, 2010) and extraversion (Eagleton et al., 2007). In another study (Khan et al., 2016), lower agreeableness was associated with better sports performance. In contrast, in a study of players of the team game League of Legends (LoL), (Matuszewski et al. 2020) players with lower ranks had significantly higher extraversion and agreeableness scores than players with higher ranks. The above data may indicate another consequence of differences in game mechanics. In League of Legends, the lower agreeableness and extraversion in the higher division group may be explained by the fact that ranking is measured by individual performance, and teams change with each ranking game, so team success is the sum of the success of independent players.In the same study, lower ranked players had lower openness scores, which may be explained by flexibility to a changing environment.

Who is a non-player? This is a person who, when joining a project, declares that he or she does not play games, or plays them infrequently, or used to play them, and currently (e.g., for 6 months) does not play.

In the study by Braun et al. (2016), in line with the direction indicated by many researchers regarding gamers' rather low neuroticism, and contrary to the study by Teng et al. (2008), non-gamers had higher levels of neuroticism than gamers, especially action game players. When one considers the number of challenges in a game, the stimulating social structure of games (especially action games), and the high anxiety and arousal that follow, it is not surprising to see lower game readiness in those with high neuroticism. While previous research has shown that playing video games can correlate with high extraversion (Amichai-Hamburger & Ben-Artzi, 2000, Tel & Sargent, 2004, Teng, 2013), Braun points out that there is no difference in extraversion levels between gamers and non-gamers. The relationship between gamification and openness remains a matter of inquiry, with some studies confirming it (Witt, Massman, & Jackson, 2010) and others not (Landers & Lounsbury, 2006). The observation that gender may be a key variable in the context of openness seems interesting in this area. Female gamers have been characterized as more open than non-gamers, while male gamers have been characterized as less open than non-gamers, which Braun et al. interpret as going beyond their gender roles in which they are expected to play or not play (Williams, Consalvo, Caplan, & Yee, 2009). Perhaps this situation has changed somewhat in the 7 years since that study - it is worth considering both social movements (e.g. #metoo) and the fact that the number of female and male gamers is equalized. According to data from the Game Story research conducted by IQS using the CAWI method: N=1000 within a nationwide study of residents of Poland aged 9-55 (N=886) and a nationwide study of players aged 9-55, in Poland in 2020, women accounted for 47% of gamers (https://grupaiqs.pl/pl/raporty/game-story).

However, on the other hand, the gaming community seems to be one that adheres to fairly conservative values (Near et al., 2013, Bègue et al. 2017), so this is not obvious. Conscientiousness in non-gamers was higher than conscientiousness in gamers, which contradicts the results reported by Teng (2008), who found a positive correlation among gamers.

3.4.6. Video Games and Cognitive Functions

Choi et al. (2020) distinguished 6 cognitive functions that, according to the study, positively correlate with playing video games: **attention, working memory, visuo-spatial function referring to perception, recognition, and manipulation of visual stimuli, probabilistic learning,** which refers to the use of declarative memory to solve uncertainty, problem solving skills, and second language learning.

However, there is still no clear evidence as to whether there is indeed a causal relationship between game experience and improved cognitive function. Meta-analyses have shown small effects of action video game experience in cross-sectional studies, but there is no meta-analytic evidence of an effect of video game training in longitudinal studies on updating (Powers et al. 2013).

Table 4. Meta-analyses results: effect of action games on cognition

Reference	Design	Games		CI	*p*	*k*
Powers et al. (2013)	Quasi-experiments	Action/ violent games	0.62	0.53 0.72	<0.001	196
Sala et al. (2018)	Correlational	Action games/ frequency +skills	0.11	0.06 0.16	<0.001	69
	Cross-sectional	Action games	0.4	0.33 0.47	<0.001	199
Bediou et al. (2018)	Cross-sectional	FPS-TPS	0.55	0.42 0.68	<0.001	194
Powers & Brooks (2014)	True experiments	FPS games	0.23	0.07 0.39	0.005	61
Powers et al. (2013)	True experiments	Action/ violent games	0.22	0.13 0.3	<0.001	135
Sala et al. (2018)	Intervention	Action vs. Non Action	0.1	-0.01 0.2	0.068	96
			-0.12	-0.25 0.01	0.072	88
Wang et al. (2017)	Intervention	Action games/ all ages	0.58	0.37 0.78	<0.001	20
		Action games/ young adults	0.75	0.43 1.07	<0.001	12
		Action games/ older adults	0.38	0.12 0.64	<0.001	8
Bediou et al. (2018)	Intervention	FPS-TPS vs. Nonaction	0.29	0.08 0.51	0.01	101
		FPS-TPS vs. Non Action/ young adults	0.34	0.07 0.61	0.02	90
		FPS-TPS vs. Non Action/ older adults	-0.36	-1.16 0.43	0.16	11

ES - effect size, CI 95% confidence interval, p - p value, m - number of studies (random effects) or clusters (RVE analysis), k - number of effect sizes.

Below is a brief description of the tasks that were included in this study: Updating Memory, Task Switching, Visual Motion Direction Discrimination and Stop Signal.

Since Star Craft II is a complex task involving multiple cognitive functions, these tasks were selected based on previous studies on Star Craft II training and recent research in the field (Doborowolski 2021, Jakubowska et al. 2019, 2021, 2022 etc.). They covered the main cognitive domains typical of VG, i.e. perception, attention and cognitive control. The battery included: Memory Updating (MU) task, measuring memory maintenance and updating, Task Switching (TS) task, measuring mental flexibility, Visual Motion Direction Discrimination (VMDD) task, measuring perceptual ability, Stop Signal (SS) task, measuring inhibitory control.

3.4.6.a Updating Memory

As video games continue to evolve, there is a growing group of researchers looking at the effects of these games on cognitive function, including updating and monitoring representations and information in working memory (Miyake et al. 2000). Updating serves to revise elements stored in working memory by replacing old information with newer and more relevant information, such as in n-back working memory tasks in which the participant is presented with a sequence of stimuli and instructed to indicate when the currently presented stimulus matches the one from n steps earlier in the sequence (Jonides and Smith 1997).
In the context of the data to date, action video players show faster and more correct responses than non-players in the n-back paradigm, indicating optimized functionality of the update function (Colzato et al. 2013). The improvement effect is even produced by logic game training in non-players (Boot et al. 2008). However, in a spatial n-back task, no increase in accuracy was registered either in action video game players compared to non-players, or after training in action games, strategy games and puzzle games for non-players (Boot et al. 2008).

3.4.6.b Task Switching

Another dimension of executive function is the relationship between action video gaming and attention switching (Berryhill and Hughes 2009, Karbach and Kray 2009, Strobach et al. 2012, Wendt et al. 2017). Attention switching (Miyake et al, 2000, Monsell 2003, Trick, Jaspers-Fayer, & Sethi, 2005) involves disengaging from irrelevant information (e.g., a set of tasks from a previous task) and/or actively engaging with relevant information (e.g., a set of tasks from an upcoming task). It requires active allocation of visual attention to target stimuli among competing distractors (Green & Bavelier, 2006) and is thought to contain a large dynamic component of attention (Scholl, Pylyshyn, & Feldman, 2001). Conclusions to date in the context of the impact of video games are inconclusive. Thus, Powers et al. (2013) and Bediou et al. (2018) indicated moderate benefits from the action video gaming experience, with the latter showing a moderating effect of subjects' age (older subjects had lower scores than younger subjects).

Experienced action video game players showed lower switching costs than non-gamers (Colzato et al. 2010) or such relationships were not seen (Boot et al. 2008, Oei & Patterson 2014, Strobach & Schubert 2021). During a training study by Strobach et al. (2012) in a pre-training task-switching performance test, switching costs did not differ between the two groups of puzzle and action game players, but post-training results indicated lower switching costs in the action game group than in the puzzle game group (Cain et al. 2012, Green et al. 2012). It has been noted that the task-switching advantage in non-gamers after video game training may be limited to situations with predictable task switches and a requirement for constant updating of working memory: how many trials have been completed in the current task and a countdown to the upcoming switch (Green et al. 2012, Strobach et al. 2012). In a task-switching paradigm with a random and unpredictable occurrence of switch and repeat attempts (e.g., a specific task is recalled), updating working memory is not required, so participants do not need to consider previous attempts. The potential positive effect of better ability to control selective attention, i.e. active engagement with relevant information about the upcoming task, has also been pointed out (Karle et al. 2010). Relevant information about the upcoming task is activated in working memory to the limited extent necessary for efficient task performance, so the effort to effectively disengage information is reduced to a minimum, freeing up processing resources for alternative tasks and potentially elevated efficiency in a complex game.

3.4.6.c. Visual Motion Direction Discrimination

Another function included in the study was visual motion direction discrimination. Researchers tested whether the sensitivity of global motion perception was affected by action video game (AVG) training (Green, Pouget, & Bavelier, 2010, Hutchinson & Stocks, 2013, Pavan, Boyce, & Ghin, 2016, Overney, Blanke, & Herzog, 2008, Kong et al., 2012). Results showed that action game players had shorter response times in a visual direction discrimination task than non-AVG players (Green et al. 2010). However, two other studies showed no effect of AVG experience on response times, even when similar tasks were used (Hutchinson & Stocks, 2013, Pavan et al., 2016).

3.4.6.d. Stop Signal

The last function considered is inhibition, which involves the ability to consciously inhibit or inhibit dominant, automatic or prepotent responses. In the context of video games, no differences were found in this regard between challenging vs. undemanding games (Engelhardt et al. 2015). Similar results were produced by cross-sectional designs as well as training (Bediou et al., 2018), as well as meta-analyses of longitudinal studies (Powers and Brook 2014). Meanwhile, in a study using Star Craft II (Dobrowolski et a. 2020), while there was no change in the training groups, a significant change occurred in the control groups, which, according to the authors, indicates a negative effect of Star Craft II training on inhibitory control. The authors also noted a negative relationship between stop signal scores and the average number of actions per minute (APM). When participants increased the number of APMs per minute in the game (which is a key component of success in RTS video games), their ability to inhibit reactions based on visual stimuli decreased. Moderation analysis confirmed that this relationship was moderated by the Star Craft II group, true for the group playing in a complex game environment, but not for the group playing in a fixed environment.

3.4.6.e. Transfer

Another important consideration here is the video game transfer effect, that is, the extent to which cognitive improvements associated with video games are transferred to untrained cognitive functions. The transfer effect of the video game experience was limited to specific baseline cognitive demands that were trained by playing video games (Baniqued et al. 2014, Oei & Patterson 2014, Oei & Patterson 2013). The most differential transfer effect was provided by action games, which activated multiple cognitive functions (e.g., attention, working memory, hand-eye coordination) by providing players with physically and mentally challenging environments (Gong et al. 2016, Oei & Patterson 2013). However, contrary to the suggestion that action games appear to improve the ability to infer the correctness of information presented in the environment, rather than improving a specific skill (Bavelier et al. 2012), it has been found that these games require various lower-level information processing skills, such as visual perception, attention skills and change detection (Oei &

Patterson 2014). Action gamers, were more efficient at tracking multiple moving objects (Oei & Patterson 2013), more efficient at improving working memory capacity, but not at improving inhibitory control (Colzato et al. 2013). The experience of playing League of Legends was associated with activation in the frontal lobe compared to activity at lower workloads (e.g., watching movies, experiencing strategy games) (Gong et a. 2019). The results suggest that video game playing does show near transfer, but not far transfer (Oei & Patterson 2014).

4. Research goals

The purpose of the dissertation is to analyze the role of player's flow in the process of complex skill learning. Components of flow include intense and focused concentration, loss of reflective self-consciousness, a sense that time has passed faster than normal, "experience of the activity as rewarding, such that often the end goal is just an excuse for the process" (Nakamura and Csikszentmihalyi, 2014). From the beginning, flow research focused mainly on sports, which was justified by the measurability of the tasks. The first two decades of the 20th century has brought an equally attractive source of data - video games (Harris, 2021), which are highly engaging and overlap with many elements of sports, such as demands on perceptual, attentional and motor skills (Campbell et al., 2018, Pedraza-Ramirez et al., 2020). Investigating flow theory in games therefore seems a natural step. The question of whether to play or not to play no longer requires an answer. As homo ludens, we know: to play. All that remains is to answer the next two questions - *who* and *how*? The question: *who?* Does a person's "baseline setting" - cognitive functioning, personality, intelligence or preference for the type of games - matter to his or her flow, and ultimately to the benefits he or she may derive from playing? The question: *how?* How to make games not only a stimulant (here we have success), but also, given their attractiveness and potential for engagement, an answer to learning difficulties or training of cognitive functions.

4. Study I. Validation of Polish Version of DFS-2 and FSS-2 Questionnaires

At the time of starting work on the project described in this thesis, there were no tools to measure the flow in Polish culture. Therefore, I undertook, with the support of Professor Aneta Brzezicka and dr Natalia Grębska-Kowalczyk, the preparation of such a tool. The immediate goal was to enable flow research in the project, while the long-term goal was to provide Polish researchers with access to reliable flow measurement tools. This made it possible to fill the gap in the analysis of processes related to the functioning of individuals and teams in different contexts, with a particular focus on learning and development processes. Interesting inspirations here include research on flow as a mediator of the relationship between attentional control and study attitudes (Cermakova et al., 2010), as a mediator between psychological possession and employees' subjective happiness (Fan et al., 2019), or consideration of the essence of flow as a mediator or moderator in the context of the impact of flow on the relationship between resources and organizational performance (Seifert, 2015). The results of the validation stude are already published (Józefowicz et al., 2022).

4.1. Methodology

4.1.1. Design of the Study

The purpose of this research was to evaluate the psychometric properties of the Polish versions of the Dispositional Flow Scale-2 (DFS-2) and Flow State Scale-2 (FSS-2) for use with Polish-speaking adults and young adults. Since there were no suitable tools available for studying flow among Polish speakers, it is important to have reliable validated measurement questionnaires. 856 questionnaires were completed by study participants, with 496 individuals participating in the DFS-2 study (with an average age of 36.31 years) and 360 individuals participating in the FSS-2 study (with an average age of 33.46 years). The study used Confirmatory Factor Analysis (CFA) and various model fit indices to assess the reliability and validity of both scales. The results showed that both DFS-2 and FSS-2 scales are reliable and valid when applied to Polish adults and young adults.

After finding a lack of flow testing tools by Polish speakers, as part of the initial consultation, available questionnaires were reviewed (Nakamura and Csíkszentmihályi, 2009, Delle Fave et al., 2011, Engeser, 2012, Moneta, 2012, Csíkszentmihályi and Larson, 2014), from which he most commonly used and validated turned out to be the **Disposition Flow Scale-2 (DFS-2)** and **Flow State Scale (FSS-2)**. DFS-2 and FSS-2 are reliable and validated tools with a long tradition in many countries, such as: France (Fournier et al., 2007), Spain (Rufi et al., 2014), Italy (Riva et al., 2017), China (Huang et al., 2019), Greece (Stavrou and Zervas, 2004).

The questionnaires translation process took place in three stages: 1. appointment of a committee of experts, 2. translation into Polish, 3. back translation. FSS-2 and DFS-2 English version questionnaires were translated by two translators, verified, and then back-translated by a native speaker and again verified by psychologists. The next step was to evaluate the psychometric properties of the questionnaires, using 496 individuals (DFS-2) and 360 individuals (FSS-2) in Polish language versions. For the purposes of the study, a license was obtained to use both questionnaires (contact with the owners of the questionnaires, Mind Garden, Inc. March 18, 2019) and the guidelines for their use "The Flow Scales Instrument and Scoring Guide" by Jackson et al. (2008).

4.1.2. Participants

Two independent groups of participants took part in the study: a. participants who agreed to participate in the DFS-2 study, b. participants who agreed to participate in the FSS-2 study. Some participants consented to both measurements. Both questionnaires were completed by Polish-speaking individuals from all over Poland (big city, town, village) over 18 years old. Due to the limitations of COVID-19, the survey was conducted in an online format, so participants had to have access to the Internet. For FSS-2, they were willing to participate in a 1.5-hour workshop where they played the online game “Symbols”. After being briefed on the study's program, participants signed an informed consent and then proceeded to play the game. For DFS-2, the task was simpler, requiring only the completion of a questionnaire. Participants made their own decisions about which of the two studies they wanted to take part in.

Recruitment for the study took place through online channels, student, volunteer, business, educational and development networks. In addition to those included in the study, 17 people (12K, 5M) who did not meet the basic eligibility requirements were not included in the study: people under the age of 18 (11K, 2M), non-native speakers (1K, 3M). Participants were recruited for the study through social media and website information.

The study included 856 participants, of which 496 participants (women N = 286, men N = 210) were recruited for the DFS-2 tool, and 360 participants (women N = 190, men N = 169, others N = 1) for the FSS-2 questionnaire survey tool. The survey participants are residents of: for DFS-2: rural areas (N = 134), cities (N = 137), towns (N = 225), for FSS-2: villages (N = 75), cities (N = 201), and towns (N = 84). Due to the large disparity between the number of applications from those with higher and primary education (98.2%-higher education), it was decided to limit the group to those with a college degree or only in the course of education (secondary education).

4.1.3. Research Materials

The Dispositional Flow Scale 2 (DFS-2) and the Flow State Scale 2 (FSS- 2) were developed by Jackson and Eklund (2002, 2004) based on earlier tools created by Jackson and Marsh (1996). These 36-item scales were developed to assess the experience of flow at the dispositional and state levels based on Csíkszentmihályi's (1990) nine-dimensional concept of flow. Both scales are a set of 36 items, consisting of 4 items for each of the 9 flow dimensions: Challenge skill balance (1), Merging of action and awareness (2), Clear goals (3), Unambiguous Feedback (4), Focus on Task at Hand (5), Sense of control (6), Loss of Self-Consciousness (7), Transformation of time (8), Autotelic experience (9). Participants were asked to indicate the degree to which they agreed with each of these items as characterizing their disposition (DFS-2) and experience of the activity just completed (FSS-2) on a Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree).

4.1.4. Procedures

Participants in the first group (a.), after being informed about the study, signed informed consent and filled out the Polish version of the DFS-2 questionnaire. Participants in the second group (b.), after being informed about the study program, signed informed consent and then proceeded to play the game "Symbols", in groups of 15-30 people, online. After completing the task, participants filled out the FSS-2 questionnaire, indicating flow as a condition. Participants played the "Symbols" game online. Each participant received (virtually) two cards with symbols. Only the owner of the cards could see their cards. The group's goal was to arrange the set of cards in the only possible position on the game board.
The first step was to figure out, using only verbal communication, how to do it (45 min), the second step was to guide the facilitator to arrange the cards in the right place according to the participants' instructions (3 min). Each participant was responsible for telling the instructor where to place each card.

The game "Symbols" was chosen from among several games that were considered due to the intensity and variable involvement of the participants. Standard informed consent procedures were followed during data collection and institutional approval was obtained for the study (Ethics Committee Opinion No: 6/2021 issued by the Research Ethics Committee of the Department of Psychology at SWPS University, Warsaw, Poland).

4.2. Results

Data Analysis

A statistical analysis of the internal compatibility of the tests was presented, the assessment of the accuracy of scales by means of confirmatory factor analysis and the analysis of the compatibility of the distribution of results with the normal distribution. In addition to the analysis of the psychometric goodness of the two questionnaires, an analysis of the DFS-2 and FSS-2 scores in terms of sociodemographic variables (gender, age, place of residence, education) was also carried out.

The analysis of the psychometric goodness of the questionnaire was conducted in the R Studio programme. As part of the psychometric goodness assessment of the tool, the internal compatibility of the tool was assessed by calculating the Cronbach α and ὼ McDonald's coefficients of each scale, the theoretical accuracy of the scales was assessed by means of confirmatory factor analysis and basic descriptive statistics were analysed together with the Shapiro-Wilk decomposition normality test. In this report, the names of some scales are shortened and presented as follows: Merging of Action and Awareness - Action and awareness, Concentration on the Task at Hand - Task concentration.

Statistical analysis of internal test compliance

The first step was to analyse reliability. The internal consistency assessment was calculated using the α Cronbach coefficient and ὼ McDonalda, it was decided to report both coefficients for fuller transparency of internal consistency. Detailed results of the analysis are presented in Table 5.

Table 5. Results of the reliability analysis for the sense of flow scales for the DFS-2 and FSS-2 questionnaire

Variable	DFS-2		FSS-2	
	α	**ώ**	**α**	**ώ**
Challenge skill balance	0.80	0.81	0.86	0.89
Action and awareness	0.75	0.79	0.76	0.78
Clear goals	0.84	0.87	0.81	0.86
Unambiguous feedback	0.79	0.83	0.85	0.87
Task concentration	0.79	0.82	0.77	0.83
Sense of control	0.83	0.85	0.86	0.87
Loss of self-consciousness	0.87	0.90	0.92	0.94
Transformation of time	0.82	0.84	0.83	0.87
Autotelic experience	0.87	0.89	0.76	0.81

Ω - McDonald's omega, α – Cronbach's alpha

Assessment of scale accuracy by means of confirmatory factor analysis

In order to assess the accuracy of the measurement scales, a confirmatory factor analysis was performed. The analysis showed that the individual dimensions are independent of each other. As a result of the analysis it was observed that the goodness of the model fit is slightly lower than the original tool, the results are summarised in Table 6.

CFI (Comparative Fit Index) slightly indicates improper model matching (CFI < 0.90), however, it is worth noting that this may be due to a small number of observations on which the analyses were made. The IASEA and SRMR indicators, on the other hand, indicate a good model match (RSMEA/SRMR < 0.08), but it is worth noting that p-value < 0.05. The significant value of the RMSEA indicator indicates that there is a high probability that the RMSEA value is different from 0 in the observed sample, but we are not able to compare this conclusion with the results from the original study, because the authors do not report confidence intervals and p-value values for the RMSEA indicator.

Table 6. CFA matching coefficients for the DFS-2 and FSS-2 questionnaire

	DFS-2	FSS-2
Model matching	X^2 (558) = 927.97 (p<0.001) RMSEA = 0.06 [0.06; 0.07] p-close = 0.001 SRMR = 0.07 CFI = 0.89	X^2 (558) =953.65 (p<0.001) RMSEA = 0.07 [0.06; 0.07] p-close < 0.001 SRMR = 0.08 CFI = 0.88
Fitting the model in the original test	X^2 (558) = 1380.96 RMSEA = 0.05 SRMR = 0.04 CFI = 0.98	X^2 (558) =1332.89 RMSEA = 0.05 SRMR = 0.05 CFI = 0.98

In Figure 4, a nine-action solution for confirmation analysis is presented. Additionally, the analysis of factor loads of each item was performed for individual scales of the DFS-2 and FSS-2 questionnaire. The value 0.3 was assumed as the cut-off criterion. It is worth noting that none of the items had a factor load below the assumed criterion.

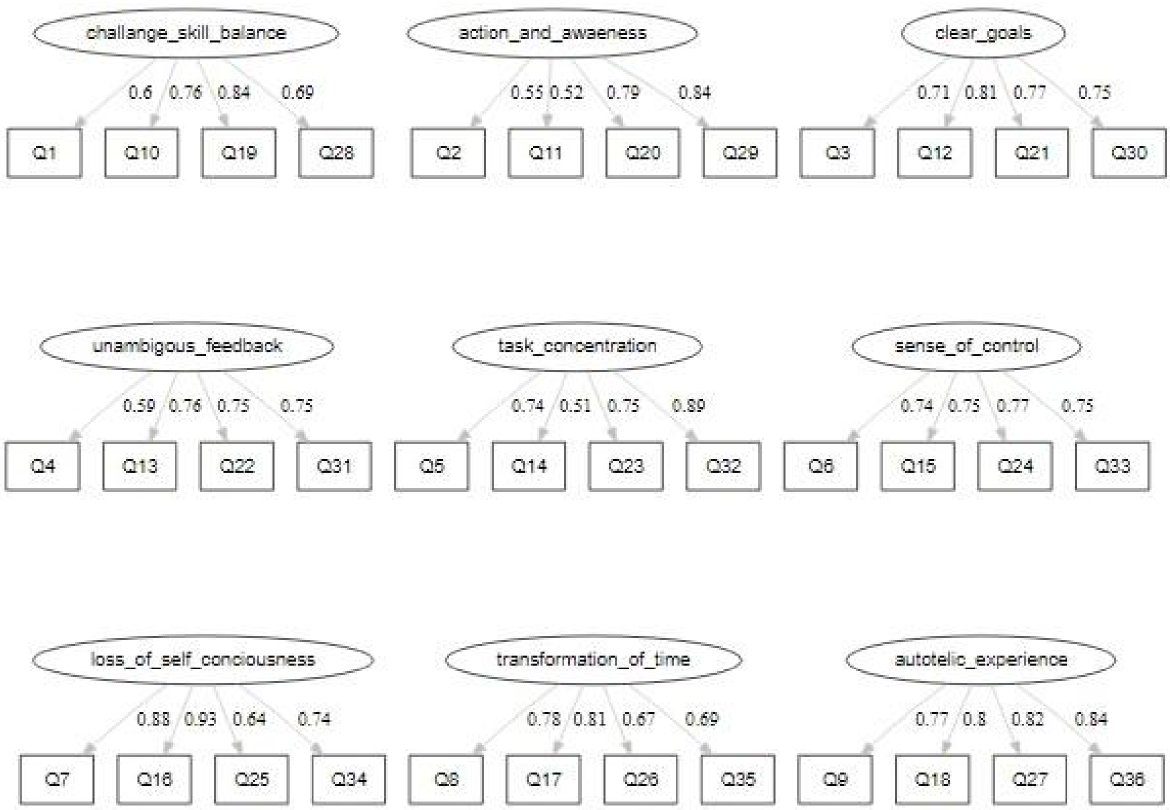


Figure 4. Confirmatory factor analysis model with standardized values of factorial loads of individual items for the DFS-2 questionnaire

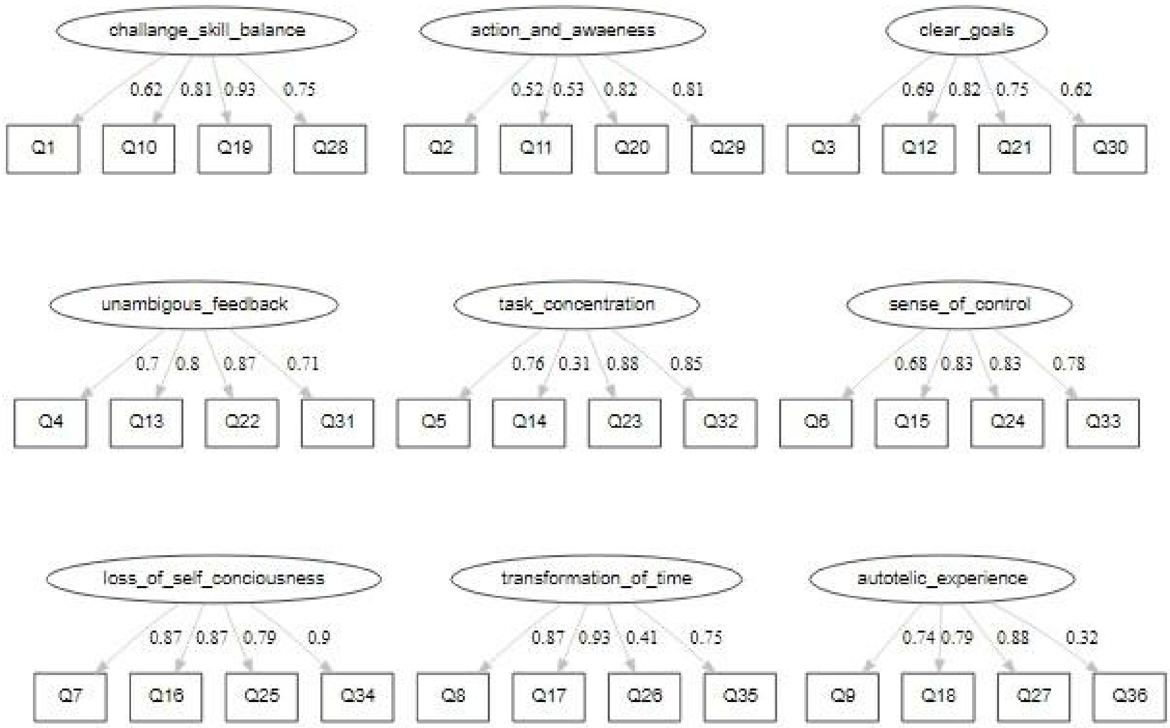


Figure 5. Confirmatory factor analysis model with standardized values of factor loads of individual items for the FSS-2 questionnaire

Table 7. Factor loadings and reliability measures for the Dispositional Flow Scale-2 models tested in the study

Dispositional Flow Dimensions		**Factor Loadings and reliability**	
	Item	**Second order, nine factors**	**First order, nine factors**
Challenge skill balance (1) **(ω = 0.83)**	**Q1** I am challenged, but I believe my skills will allow me to meet the challenge	0.63	0.63
	Q10 My abilities match the challenge of what I am doing	0.74	0.73
	Q19 I feel I am competent enough to meet the high demands of the situation	0.83	0.84
	Q28 The challenge and my skills are at an equally high level	0.75	0.74

Merging of Action and awareness (2) **(ω = 0.77)**	**Q2** I make the correct movements without thinking about trying to do so	0.59	0.53
	Q11 Things just seem to happen automatically	0.54	0.53
	Q20 I do things automatically, without thinking too much	0.8	0.74
	Q29 I do things spontaneously and automatically without having to think	0.84	0.85
Clear goals (3) **(ω = 0.88)**	**Q3** I know clearly what I want to do	0.77	0.74
	Q12 I have a strong sense of what I want to do	0.83	0.84
	Q21 I know what I want to achieve	0.83	0.83
	Q30 My goals are clearly defined	0.77	0.80
Unambiguous feedback (4) **(ω = 0.85)**	**Q4** It is really clear to me how I am doing	0.75	0.72
	Q13 I am aware of how well I am doing	0.83	0.8
	Q22 I have a good idea about how well I am doing while I am involved in the task/activity	0.88	0.82
	Q31 I can tell by the way things are progressing how well I am doing	0.73	0.71
Task Concentration (5) **(ω = 0.80)**	**Q5** My attention is focused entirely on what I am doing	0.82	0.75
	Q14 It is no effort to keep my mind on what is happening	0.19	0.39
	Q23 I have total concentration	0.87	0.82
	Q32 I am completely focused on the task at hand	0.91	0.88
Sense of Control (6) **(ω = 0.87)**	**Q6** I have a sense of control over what I am doing	0.77	0.71
	Q15 I feel like I can control what I am doing	0.83	0.78
	Q24 I have a feeling of total control over what I am doing	0.9	0.83
	Q33 I feel in total control of my actions	0.86	0.8
Loss of self consciousness (7) **(ω = 0.9)**	**Q7** I am not concerned with what others may be thinking of me	0.86	0.88
	Q16 I am not concerned with how others may be evaluating me	0.64	0.64
	Q25 I am not concerned with how I am presenting myself	0.87	0.86

	Q34 I am not worried about what others may be thinking of me	0.9	0.9
Transformation of time (8)	**Q8** Time seems to alter (either slows down or speeds up)	0.83	0.73
(ω = 0.83)	**Q17** The way time passes seems to be different from normal	0.91	0.83
	Q26 It feels like time goes by quickly	0.6	0.63
	Q35 I lose my normal awareness of time	0.82	0.74
Autotelic experience (9)	**Q9** I really enjoy the experience of what I am doing	0.81	0.71
(ω = 0.88)	**Q18** I love the feeling of the performance and want to capture it again	0.82	0.82
	Q27 The experience leaves me feeling great	0.93	0.85
	Q36 The experience is extremely rewarding	0.66	0.83

Table 8. Factor loads of individual items for the Polish Flow State Scale (PFSS-2)

Dispositional Flow Dimensions		**Factor Loadings and reliability**	
	Item	**Second order, nine factors**	**First order, nine factors**
Challenge skill balance	**Q1** I was challenged, but I believed my skills would allow me to meet the challenge	0.64	0.64
(ω = 0.87)	**Q10** I was challenged, but I believed my skills would allow me to meet the challenge	0.87	0.86
	Q19 I felt I was competent enough to meet the demands of the situation	0.9	0.9
	Q28 The challenge and my skills were at an equally high level	0.77	0.78
Merging of Action and awareness (2)	**Q2** I did things correctly without thinking about trying to do so	0.59	0.59
(ω = 0.80)	**Q11** Things just seemed to be happening automatically	0.54	0.55

	Q20 I did things automatically, without thinking too much	0.8	0.8
	Q29 I did things spontaneously and automatically without having to think	0.84	0.83
Clear goals (3) (ω = 0.88)	**Q3** I knew clearly what I wanted to do	0.77	0.76
	Q12 I had a strong sense of what I wanted to do	0.83	0.83
	Q21 I knew what I wanted to achieve	0.83	0.83
	Q30 My goals were clearly defined	0.77	0.78
Unambiguous feedback (4) (ω = 0.87)	**Q4** It was really clear to me how I was doing	0.75	0.75
	Q13 I was aware of how well I was doing	0.83	0.83
	Q22 I had a good idea about how well I was doing while I was involved in the task/activity	0.88	0.88
	Q31 I could tell by the way things were progressing how well I was doing	0.73	0.73
Concentration on the Task at Hand (5) (ω = 0.79)	**Q5** My attention was focused entirely on what I was doing	0.82	0.82
	Q14 It was no effort to keep my mind on what was happening	0.19	0.18
	Q23 I had total concentration	0.87	0.87
	Q32 I was completely focused on the task at hand	0.91	0.9
Sense of Control (6) (ω = 0.91)	**Q6** I had a sense of control over what I was doing	0.77	0.76
	Q15 I felt like I could control what I was doing	0.83	0.84
	Q24 I had a feeling of total control over what I was doing	0.9	0.9
	Q33 I felt in total control of my actions	0.86	0.86
Loss of self consciousness (7) (ω = 0.92)	**Q7** I was not concerned with what others may have been thinking of me	0.86	0.86
	Q16 I was not concerned with how others may have been evaluating me	0.88	0.88
	Q25 I was not concerned with how I was presenting myself	0.81	0.81
	Q34 I was not worried about what others may have been thinking of me	0.91	0.91

Transformation of time (8)	**Q8** Time seemed to alter (either slowed down or speeded up)	0.74	0.83
(ω = 0.88)	**Q17** The way time passed seemed to be different from normal	0.82	0.91
	Q26 It felt like time went by quickly	0.64	0.6
	Q35 I lost my normal awareness of time	0.74	0.82
Autotelic experience (9)	**Q9** I really enjoyed the experience of what I was doing	0.81	0.82
(ω = 0.86)	**Q18** I loved the feeling of what I was doing, and want to capture this feeling again	0.82	0.82
	Q27 The experience left me feeling great	0.93	0.92
	Q36 I found the experience extremely rewarding	0.66	0.65

The Challenge skill balance scale is characterised by satisfactory factorial loads for all items for both DFS-2 and FSS-2. The test items were observed to be internally consistent and similar load capacities between the tools were observed. In both questionnaires the strongest factor load is Q19, while the weakest Q1.

Items on the action and awareness scale are also characterised by satisfactory factor loads for the DFS-2 and FSS-2. The strongest factor load for both tools is Q29, while the weakest factor load on the DFS-2 scale is Q11 and on the FSS-2 scale Q2.

All items on the clear goals scale are characterized by high value of standardized factorial loads. The item Q30 in the FSS-2 scale is characterized by a significantly lower value of factor load compared to the DFS scale, however, its value in both scales is at a satisfactory level.

All items on the unambiguous feedback scale are also characterized by high value of standardized factorial loads. The item Q4 on the DFS-2 scale has a significantly lower value of the factor load compared to the FSS-2 scale, but its value is high on both scales.

All items of the Concentration on the Task at Hand scale are characterized by satisfactory value of factorial loads. A very low value of the factor load was observed for Q14 position, for this position an in-depth analysis of the discriminating power was performed using rho Spearman correlation analysis with the rest of the scale. The results indicate that item Q14 has a moderate discriminating power (rho = 0.59; $p < 0.001$).

Additionally, the number of data missing for a given item was checked and one observation was observed which should not affect the power of standardized factor load of a given test item.

All Sense of control and Loss of self-consciousness scale items are characterized by a satisfactory value of factorial charges of similar value for both tools.

The factorial charges of the individual items of the *Transformation of time* scale also have a satisfactory value. The position with the lowest factor load for both tools is Q26, due to the low factor load power for the FSS-2 scale, the discriminatory power of a given test item was checked by means of the rho Spearman position correlation test with the rest of the scale, and data gaps were checked. No missing observations were observed for the item and its discriminatory value is moderate (rho = 0.59, $p < 0.001$).

Autotelic experience scale positions are mostly characterised by high factorial loads. The lowest value of standardized factor load for a given scale is characterized by item Q36 for the FSS-2 tool, due to the very low value of factor load an additional analysis of the discriminating power of a given item was performed and the number of data gaps was checked. The discriminatory power of the test item is high (rho = 0.76; $p < 0.001$).

Analysis of the compatibility of the distribution of results with the normal distribution

In the last step of the statistical analysis, basic descriptive statistics for the different scales of the tool were made, together with a check on the normal distribution of results. The results were observed collectively for the DFS-2 tool in Table 9 a and for the FSS-2 tool in Table 9 b. Compliance of the distribution of results with the normal distribution was carried out using the Shapiro-Wilk test, the test statistics indicate that the distribution of results of all scales differs from the normal distribution, both for the DFS-2 and FSS-2 questionnaires. It is worth noting, however, that the value of the obliqueness does not exceed the conventional value of -1 to 1. It is also reasonable to state that the distributions of the observed results differ slightly in shape from the normal distribution.

Table 9. Descriptive statistics with the Shapiro-Wilk decomposition normality test for the DFS-2 (a) and FSS-2 (b) questionnaire scale

a. DFS-2	*M*	*Mdn*	*SD*	*Sk.*	*Kurt.*	*Min.*	*Maks.*	*S-W*	*p*
Challenge skill balance	15.71	16.00	2.34	-0.45	0.16	8	20	0.97	<0.001
Action and awareness	13.38	13.00	2.86	0.02	-0.52	7	20	0.98	0.012
Clear goals	15.95	16.00	2.61	-0.54	0.26	8	20	0.95	<0.001
Unambiguous feedback	15.49	16.00	2.40	-0.09	-0.13	9	20	0.96	<0.001
Task concentration	15.35	15.00	2.72	-0.36	-0.04	8	20	0.97	<0.001
Sense of control	15.20	16.00	2.59	-0.13	-0.48	8	20	0.97	0.001
Loss of self-consciousness	13.19	14.00	3.99	-0.47	-0.51	4	20	0.96	<0.001
Transformation of time	14.70	15.00	3.29	-0.43	0.36	4	20	0.96	<0.001
Autotelic experience	16.38	17.00	2.98	-0.45	-0.88	9	20	0.92	<0.001

b. FSS-2	*M*	*Mdn*	*SD*	*Sk.*	*Kurt.*	*Min.*	*Maks.*	*S-W*	*p*
Challenge skill balance	14.95	16	3.42	-0.61	0.07	5	20	0.95	<0.001
Action and awareness	13.12	13	3.30	0.06	-0.54	5	20	0.98	0.033
Clear goals	15.16	16	3.29	-0.80	0.47	5	20	0.94	<0.001
Unambiguous feedback	14.75	15	3.41	-0.72	0.60	5	20	0.95	<0.001
Task concentration	15.33	16	3.12	-0.85	0.72	4	20	0.94	<0.001
Sense of control	14.44	15	3.48	-0.47	-0.21	4	20	0.97	<0.001
Loss of self-consciousness	14.78	16	4.71	-0.54	-0.81	4	20	0.90	<0.001
Transformation of time	12.93	13	4.14	-0.30	-0.65	4	20	0.97	0.002
Autotelic experience	13.31	13	3.74	-0.16	-0.49	5	20	0.97	0.006

Sociodemographic variables vs. DFS-2 results

The results of DFS-2 factors in relation to sociodemographic variables were evaluated. Table 10 presents the analysis of the Student's t test for independent data between women and men.

Table 10. Summary of the analysis of the Student's t-test analysis for independent samples of DFS-2 between women and men

DFS - factor	Women *N* = 88		Men *N* = 78		$t_{(164)}$	*p*
	M	*SD*	*M*	*SD*		
Challenge-Skill Balance	15,74	2,2	15,69	2,49	0,127	0,899
Action and Awareness	13,64	2,67	13,09	3,05	1,232	0,220
Clear Goals	16,02	2,38	15,88	2,84	0,341	0,734
Unambiguous Feedback	15,44	2,41	15,54	2,39	-0,255	0,799
Task Concentration	15,33	2,69	15,37	2,77	-0,100	0,921
Sense of Control	15,22	2,4	15,22	2,81	-0,005	0,996
Loss of Self-Consciousness	13,76	3,57	12,59	4,35	1,904	0,059
Transformation of Time	14,84	3,18	14,54	3,43	0,590	0,556
Autotelic Experience	16,61	3,02	16,13	2,93	1,049	0,296

N - number of observations, M - average, SD - standard deviation, t - Student's test value for independent samples, p - level of statistical significance

The result of the analyses showed that women and men do not differ in the result of any of the DFS-2 factors. A similar one-factor analysis of variance was carried out for DFS-2 factors in groups of different ages. The results of this analysis are presented in table 11.

Table 11. Summary of single-factor analysis of variance of DFS-2 factors in groups of subjects of different age range

DFS-factor	18-34 years (1) *N* = 84		35-44 years (2) *N* = 43		45-72 years (3) *N* = 39		$F_{(2, 163)}$	*p*	post hoc
	M	*SD*	*M*	*SD*	*M*	*SD*			
Challenge-Skill Balance	15,08	2,46	16,51	2,09	16,21	1,95	**6,911**	**0,001**	**1<2,3**
Action and Awareness	13,02	2,65	13,77	3,35	13,72	2,67	1,326	0,268	--
Clear Goals	15,45	2,73	16,53	2,69	16,41	1,97	**3,330**	**0,038**	**1<2**
Unambiguous Feedback	14,87	2,36	16	2,39	16,26	2,15	**6,178**	**0,003**	**1<2,3**
Task Concentration	14,93	2,58	15,37	3,14	16,23	2,33	**3,136**	**0,046**	**1<3**
Sense of Control	14,5	2,57	15,49	2,67	16,46	2,02	**8,688**	**<0,001**	**1<2,3**

Loss of Self-Consciousness	12,5	4,13	13,79	4,27	14,1	3,04	2,826	0,062	--
Transformation of Time	13,96	3,38	15,47	3,25	15,44	2,81	**4,417**	**0,014**	**1<2,3**
Autotelic Experience	15,64	3,03	17,19	2,95	17,1	2,51	**5,599**	**0,004**	**1<2,3**

Annotation. Post hoc analysis using the NIR test.; N - number of observations, M - mean, SD - standard deviation, F - value of variance analysis, p - level of statistical significance

The analysis showed that subjects of different ages differ in the results of the Challenge-skill balance, Unambiguous feedback, Sense of control, Transformation of time and Autotelic experience scales in such a way that subjects aged 18-34 have significantly lower results than subjects aged 35-44 and 45-72. There is no significant difference for these variables between the age groups 35-44 and 45-72. In addition, subjects aged 18-34 achieve significantly lower scores for the Clear of goals scale than the 35-44 age group and for the Concentration on the task scale than the 45-72 age group.

Another element of the evaluation of the DFS-2 tool was the analysis of the differences in its results by persons with different places of residence. The one-factor analysis of variance used for this purpose is presented in Table 12.

Table 12. Summary of the one-factor analysis of variance of the DFS-2 factors in the division into respondents with different places of residence

DFS-factor	Village (1) *N* = 50		Town (2) *N* = 62		City (3) *N* = 54		$F_{(2, 163)}$	*p*	post hoc
	M	*SD*	*M*	*SD*	*M*	*SD*			
Challenge-Skill Balance	16,16	1,99	15,79	2,71	15,22	2,09	2,178	0,117	--
Action and Awareness	13,44	2,93	13,63	2,90	13,04	2,75	0,633	0,532	--
Clear Goals	16,48	2,27	15,89	2,78	15,56	2,63	1,693	0,187	--
Unambiguous Feedback	15,54	1,91	15,69	2,79	15,2	2,32	0,620	0,539	--
Task Concentration	15,80	2,45	15,26	3	15,04	2,61	1,079	0,342	--
Sense of Control	15,50	2,01	15,48	2,84	14,65	2,71	1,950	0,146	--
Loss of Self-Consciousness	13,40	4,30	13,39	4,11	12,83	3,58	0,356	0,701	--
Transformation of Time	14,96	3,16	15,1	3,25	14	3,39	1,849	0,161	--
Autotelic Experience	17,06	2,7	16,56	2,98	15,56	3,08	**3,607**	**0,029**	**1>3**

Annotation. Post hoc analysis using the NIR test.; N - number of observations, M - mean, SD - standard deviation, F - value of variance analysis, p - level of statistical significance

The results of the analyses showed that the respondents with different places of residence achieve significantly different results only for the Autotelic experience scale. Residents living in rural areas achieve significantly higher results on this scale than those from a large city. The other DFS-2 scales do not differ in the results between respondents with different places of residence.

The last sociodemographic factor was the education of the respondents. Differences in the results of the DFS-2 tool between respondents with secondary and higher education were tested with Student's t test for independent data, which is summarized in Table 13.

Table 13. Summary of the analysis with Student's t test for independent samples of the DFS-2 tool between respondents with secondary and higher education

DFS-factor	Secondary $N = 51$		Higher $N = 115$		$t_{(164)}$	p
	M	*SD*	*M*	*SD*		
Challenge-Skill Balance	15,18	2,54	15,96	2,2	**-2,006**	**0,047**
Action and Awareness	13,16	2,74	13,48	2,92	-0,667	0,505
Clear Goals	15,14	3,12	16,32	2,25	**-2,763**	**0,006**
Unambiguous Feedback	15,08	2,46	15,67	2,35	-1,475	0,142
Task Concentration	14,9	2,71	15,55	2,71	-1,416	0,159
Sense of Control	14,67	2,66	15,46	2,53	-1,835	0,068
Loss of Self-Consciousness	12,37	4,36	13,58	3,77	-1,816	0,071
Transformation of Time	14,47	3,13	14,8	3,36	-0,594	0,553
Autotelic Experience	15,55	3,08	16,76	2,86	**-2,448**	**0,015**

N - number of observations, M - mean, SD - standard deviation, t - Student's test value for independent samples, p - statistical significance level

The analysis showed that people with higher and secondary education differ only in the results of the Challenge-skill balance, Clear goals and Autotelic experience. Persons with higher education achieve much higher scores for these scales than those with secondary education.

Sociodemographic variables and FSS-2 test results

Similarly to DFS-2, the results of the FSS-2 factors in relation to sociodemographic variables were evaluated. Table 14 presents the analysis of the Student's t test for independent samples between women and men.

Table 14. Summary of the analysis with the Student's t-test analysis for the data of independent samples of the FSS-2 tool between women and men

FSS-2- factor	Women *N* = 81		Men *N* = 75		$t_{(154)}$	*p*
	M	*SD*	*M*	*SD*		
Challenge-Skill Balance	15,12	3,72	14,76	3,08	0,662	0,509
Action and Awareness	13,28	3,55	12,95	3,02	0,636	0,525
Clear Goals	15,54	3,34	14,80	3,21	1,415	0,159
Unambiguous Feedback	15,12	3,54	14,35	3,23	1,427	0,156
Task Concentration	15,41	3,13	15,33	3,03	0,150	0,881
Sense of Control	14,83	3,51	14,07	3,40	1,373	0,172
Loss of Self-Consciousness	15,59	4,73	13,89	4,55	**2,283**	**0,024**
Transformation of Time	12,06	4,56	13,91	3,38	**-2,851**	**0,005**
Autotelic Experience	14,25	3,71	14,65	3,13	-0,737	0,462

N - number of observations, M - mean, SD - standard deviation, t - Student's test value for independent samples, p - statistical significance level

The analysis presented showed that the women surveyed score higher than men on the Loss of Self-Consciousness scale. This is different for the Transformation of time scale, where men scored higher than women. For the other scales of the FSS-2 tool, there are no significant differences between women and men.

Then, a one-factor analysis of variance was evaluated in the DFS tool factors in groups of respondents of different ages. Table 15 presents the results of this analysis.

Table 15. Summary of the single-factor analysis of variance of the FSS-2 factors in the examined groups at different ages

FSS-2 - factor	18-34 years (1) $N = 81$		35-44 years (2) $N = 40$		45-72 years (3) $N = 35$		$F_{(2, 153)}$	*p*	post hoc
	M	*SD*	*M*	*SD*	*M*	*SD*			
Challenge-Skill Balance	14,89	3,37	15,58	3,22	14,37	3,75	1,183	0,309	--
Action and Awareness	12,93	3,07	13,48	3,43	13,17	3,70	0,373	0,690	--
Clear Goals	15,32	3,41	14,9	3,39	15,2	2,93	0,218	0,805	--
Unambiguous Feedback	14,59	3,22	15,3	3,46	14,49	3,80	0,709	0,494	--
Task Concentration	15,4	2,75	15	3,67	15,74	3,08	0,548	0,580	--
Sense of Control	14,35	3,57	14,45	3,75	14,74	2,93	0,159	0,853	--
Loss of Self-Consciousness	13,53	4,93	15,65	4,19	16,66	3,95	**6,789**	**0,001**	**1<2,3**
Transformation of Time	12,72	3,78	13,9	4,44	12,40	4,49	1,508	0,225	--
Autotelic Experience	14,46	3,35	14,85	3,07	13,94	4,01	0,649	0,524	--

Annotation. Post hoc analysis using the NIR test.

N - number of observations, M - mean, SD - standard deviation, F - value of variance analysis, p - level of statistical significance

The results of the analyses showed that the subjects aged 18-34 achieve significantly lower results of the scale of Loss of self-consciousness than the 35-44 and 45-72 age groups. The remaining FSS-2 scales will not differ significantly between respondents of different ages.

Another element of evaluation of the FSS-2 tool was the analysis of differences in its results by persons with different places of residence. The one-factor analysis of variance used for this purpose is presented in Table 16.

Table 16. Summary of single-factor analysis of factor variance of the FSS-2 tool broken down into respondents with different places of residence

FSS-2 - factor	Village (1) $N = 45$		Town (2) $N = 60$		City (3) $N = 51$		$F_{(2, 153)}$	*p*	ost hoc
	M	*SD*	*M*	*SD*	*M*	*SD*			
Challenge-Skill Balance	14,58	2,77	15,18	3,7	15	3,64	0,408	0,666	--
Action and Awareness	12,84	2,9	13,5	3,55	12,92	3,35	0,644	0,527	--
Clear Goals	14,89	2,61	15,3	3,91	15,31	3,06	0,256	0,775	--
Unambiguous Feedback	13,62	3,39	15,33	3,37	15,06	3,29	**3,673**	**0,028**	**1<2,3**
Task Concentration	15,4	2,96	15,37	3,26	15,35	3	0,003	0,997	--
Sense of Control	13,87	3,3	14,85	3,46	14,53	3,61	1,050	0,353	--
Loss of Self-Consciousness	15,58	3,99	14,82	5	14,02	4,91	1,319	0,271	--
Transformation of Time	13,49	3,54	12,65	4,68	12,82	3,96	0,562	0,571	--
Autotelic Experience	14,33	3,25	14,83	3,49	14,08	3,55	0,694	0,501	--

Annotation. Post hoc analysis using the NIR test.

N - number of observations, M - mean, SD - standard deviation, F - value of variance analysis, p - level of significance

The analysis carried out showed that the inhabitants of towns and cities achieve significantly higher results of Unambiguous feedback than the inhabitants of villages. The respondents living in villages, towns and cities do not seem to differ in the results of the other FSS-2 scales.

Here also the last sociodemographic factor was the respondents' education. Differences in FSS-2 results between respondents with secondary and higher education were tested with the Student's t test for independent data, which is summarised in the table 17.

Table 17. Summary of the analysis with the Student's t test for independent data of the FSS-2 tool between respondents with secondary and higher education

FSS-2-factor	Secondary $N = 46$		Higher $N = 110$		$t_{(154)}$	*p*
	M	*SD*	*M*	*SD*		
Challenge-Skill Balance	15,52	2,80	14,71	3,64	1,356	0,177
Action and Awareness	13,00	3,19	13,17	3,36	-0,297	0,767
Clear Goals	15,59	3,19	15,02	3,33	0,985	0,326
Unambiguous Feedback	15,22	2,62	14,55	3,68	1,108	0,269
Task Concentration	15,26	2,93	15,42	3,14	-0,291	0,772
Sense of Control	14,76	2,88	14,34	3,69	0,696	0,487
Loss of Self-Consciousness	12,89	4,89	15,56	4,42	**-3,337**	**0,001**
Transformation of Time	13,04	3,85	12,91	4,26	0,185	0,854
Autotelic Experience	14,54	2,99	14,40	3,62	0,237	0,813

N - number of observations, M - mean, SD - standard deviation, t - Student's test value for independent samples, p - statistical significance level

The analyses carried out have shown that the participants with higher education achieve significantly higher Loss of self-consciousness scores than the participants with secondary education. The participants with secondary and higher education turned out not to differ in the results of other FSS-2 tool scales.

4.3. Discussion & Conlusions

Our findings confirmed the reliability and validity of the Polish versions of DFS-2 and FSS-2 scales. The scales are reliable when applied to Polish adults and young adults. Thanks to the research outlined earlier, a robust adaptation of PDFS-2 and PFSS-2 for Polish-speaking adults has been developed. The study of flow enables us to comprehend experiences in which individuals are completely absorbed in the present moment of a task.
Since the publication of the validated tool, the publication has attracted a lot of interest, as evidenced by the high number of page views (about 4,000 in 1 year) and submissions from 14 research teams that are currently conducting research using the validated questionnaires.

Working on the preparation of the validation, we looked at possible directions of inquiry and, as a result, the analysis of the literature and our own observations identified 3 directions:

1. Criterion-related validity (Kline, 2005) using self-report tools of other psychological constructs (motivation, immersion, commitment, self-esteem, locus of control) or variables (level of participation and skills).
2. Verify the stability of the questionnaires. It seems interesting to verify the extent to which the measurement for a given participant is stable. Although the nature of the PFSS-2 tool suggests that it relates to the "here and now," it would be interesting to observe whether there are trends within a person's measurement.
3. Verify the correlation between the PDFS-2 and PFSS-2. Another interesting direction seems to be the implementation of group studies using both questionnaires (PDFS-2 and PFSS-2).

Interesting directions of flow analysis have been included in the studies described later in the thesis. They can make an important and rare - due to the longitudinal nature of the research and the rich compilation of tools - contribution to the development of knowledge about the flow phenomenon.

4.4. Limitations

A key limitation may be the fact that the survey was conducted online and the questionnaires were completed electronically.

5. Study II. What is the role of player's flow in learning complex skills in a form of a video game?

5.1. Methodology

The implementation of a large project in the Games Lab provided an opportunity to look at many video games and players from different perspectives. In addition to hard cognitive and physiological data, fleeting factors related to player well-being, such as flow or task load perception, were of interest. It seemed clear that in the case of such an intensive task as 60 hours of gameplay, plus measurements, participants would experience various states which - at the level of a sense of purpose, the need for control, or balance, and thus summing up - flow - would likely influence the way they play and their results in the game.

5.1.1. Design of the Study

The data presented in this part of the thesis are part of the bigger project titled '***The temporal dynamics of neurocognitive changes induced by complex task training in the form of strategic computer game***' awarded to Aneta Brzezicka, PhD, professor at SWPS, and conducted at the Neurocognitive Research Center (SWPS University in Warsaw). Project number 2016/23/B/HS6/03843, founded by the National Science Center. The research was approved by the Ethics Committee of SWPS University (number: 38/2018). All subjects signed an informed consent in accordance with the Declaration of Helsinki, before the first measurement session, to participate in the study.

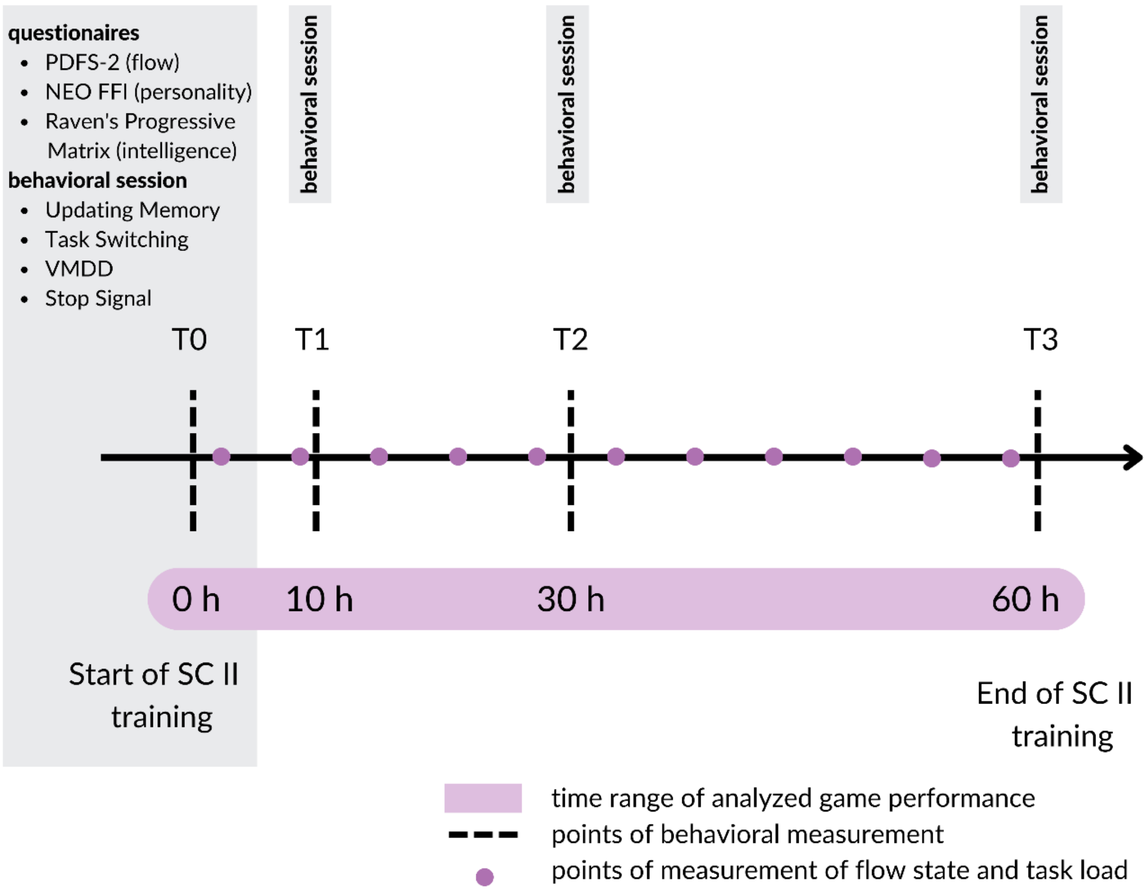


Figure 6. Graphic presentation of the study design

This longitudinal study employed a training regimen to instigate cognitive and neural alterations in a healthy cohort, with comprehensive evaluation points to track these changes (see Figure 4). Aligning with the "gold standard" recommended by Simon's et al. (2016), it used a randomized double-blind design and an apt control group.

The focus of my research in this project was on the potential impact of a player's flow on their gaming behaviour as well as on the effectiveness of the VG-based cognitive training, an aspect suggested by previous studies but not fully explored. Using StarCraft II as the cognitive training task, participants were divided into three groups: Variable Environment Group (VEG), Fixed Environment Group (FEG), and a control group. The VEG and FEG underwent 60 hours of training each over ten weeks, with repeated measurements taken.

Multiple instruments were used to assess changes in participants' cognitive functioning, including behavioral tasks, MRI, EEG, and gameplay data. However, this thesis does not include MRI and EEG data. A suite of cognitive tasks was developed by the research team to evaluate the quality of cognitive changes.

Several cognitive functions were targeted, including perception, attention, and cognitive control. These were assessed using tasks like Memory Updating (MU), Task Switching (TS), Visual Motion Direction Discrimination (VMDD), and Stop Signal (SS). All were computerized, except for the paper-based Raven's matrices.

Behavioral Measures	**Indicators**
NEO FFI (McCrae & Costa 2010)	Personality inventory
Raven’s Advanced Progressive Matrices (Raven et al., 2003)	Fluid intelligence
Visual Working Memory (Vogel & Machizawa, 2004)	Change discrimination after retention period
Visual Motion Discrimination (Palmer, Huk, & Shadlen, 2005)	Discrimination of motion direction at different levels of coherence
Stop Signal Task (Verbuggen et al., 2008)	Ability to inhibit already initiated motor response
Memory Updating (Salthouse et al., 1991)	Updating ability of working memory
PDFS2, PFSS-2 (Józefowicz et al. 2022)	Dispositional flow and flow as a state
NASA TLI (Human Performance Group at NASA's Ames Research Center 1986)	Perceived workload in order to assess a task, system, or team's effectiveness or other aspects of performance

Data collection occurred at four key points and during the training with the SCII game. Key points: before the training (T0), after 10 hours (T1), 30 hours (T2), and post-training (T3). Results thus far suggest StarCraft II may enhance cognitive functioning in non-gamers, indicating that the chosen tasks effectively measure relevant cognitive domains. During the course of the games, approximately **every 5.45 hours** (a maximum of 11 times), participants were asked to fill out questionnaires, regarding their flow status and task load. During the game, the Star Craft II system also collected telemetry data.

During each behavioral session, participants completed seven tasks in a specific order and were allowed water and short breaks. They were asked to mute their phones and fill out a questionnaire after each task. Their unique ID was scanned from a code card to maintain consistent tracking. The first session was longer due to the inclusion of tasks measured only once (NEO FFI and Raven Matrix).

5.1.2. Participants

5.1.2.a. Recruitment and sampling strategy

The inclusion criteria for the participants were: little or no previous experience with RTS video games, experience with non-RTS types of video games of no more than 8 h/week in the past six months, no history of neurological diseases (declaration), no history of psychoactive substance use, normal eyesight and hearing, right-handedness and normal or corrected-to-normal vision and hearing.

Participants were recruited mainly through Facebook advertising campaigns that invited individuals to participate in a longitudinal study on learning complex skills. Potential participants were surveyed online via the GEX platform (GEX Immergo, Funds Auxilium Ltd.) using the VGQ (Video Game Questionnaire, Sobczyk et al., 2015) to assess their video game playing history. The questionnaire included questions about age, gender, education level, marital status, work experience, total experience with video games in years, frequency of playing video games, devices used to play video games, game genres played by participants, subjective level of knowledge about games, and frequency of playing particular game genres. Prior to the MRI study, they completed questionnaires regarding their health status.

Only subjects, who had no previous exposure to real-time strategy and SC games were included in the study and who reported having played action video games (first-person shooter, third-person shooter, open-world action games, and multi-player online battle arenas) less than 8 h per week in the past 6 months were accepted into the study and invited for laboratory measurements. They were also asked about previous experience with FPS games, with only one participant reporting playing FPS in the past. None of the participants declared having played action games in the 6 months prior to recruitment.

Written informed consent was obtained from each participant prior to the start of training and information was provided regarding their rights as voluntary participants in the study, in accordance with the Declaration of Helsinki. Participants were asked to refrain from playing other video games during the study.

Participants received financial compensation for their participation in the study.

5.1.2.b. Sample size

The design assumed 66 subjects divided into 3 groups (3 x N = 22). The assumed sample size was determined based on typical effect sizes found in the literature on video games and cognition, which oscillate around d = 0.8. Assuming a statistical power of 0.8 and an alpha level of 0.05, the minimum size of each group should be n = 21 (the project initially assumed n = 22) according to the guidelines described by Soper (2013).

A total of 73 subjects took part in the study. The final sample consisted of 41 participants (female = 28) with a mean age = **28 years** (SD = 5.11), of which the results of **29 people** were included in the flow study (SD = 4.95). The control group in the context of the this project was not included, as they had no exposure to video games and no flow measurements. For the VEG training group, the control group in the study dealing with flow was the FEG group.

The group size is low, however, as shown in a meta-analysis by Harris et a. (2020)-adequate or lower was included in similar studies: N = 33 (Harris et al., 2017), N = 24 (Schattke et al., 2014), N = 20 (Schmidt et al., 2020), and even N = 9 (Cowley et al. (2019). It is worth mentionning that gathering data from a single participant took roughly 90 hours of experimental work (and required three months of participant's engagement), what is also important, data from 16 subjects was incomplete due to pandemic (see Table 18 for detailed description of dropouts reasons).

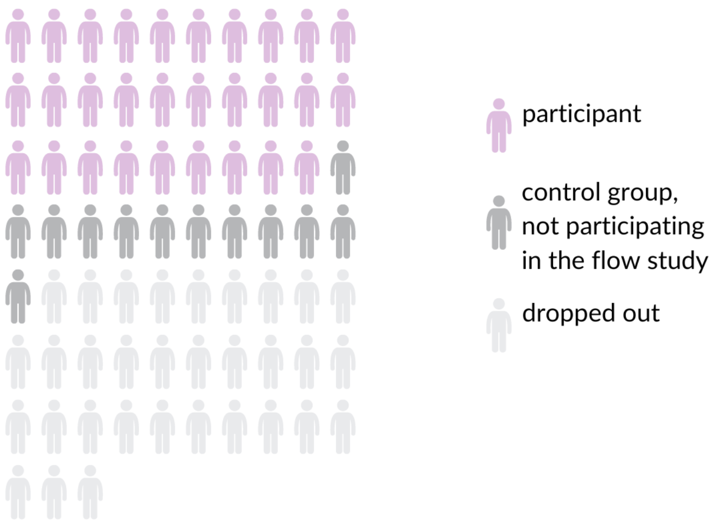


Figure 7. Proportion of recruited participants to retained participants

A total of 73 people passed the recruitment process, of which **32 dropped out** (Table 18).

Tabel 18. Summary of the cause of drop out in the project

The cause of the drop out	**Number of People**
pandemic - change in living conditions (health issues, fear of COVID-19 virus infection, moving, taking a job, leaving the Warsaw area)	7
pandemic - the person does not respond to contact attempts	9
war in Ukraine (leaving the vicinity of Warsaw, taking commitments, related to helping people, affected by the war)	3
retention apparatus interfering with MRI images	1
reluctance to train	3
failure of the participant to fulfill the terms of the contract (failure of the participant to participate in the measurements at the specified time intervals)	5
candidate's decision not to sign the contract	4

5.1.2.c. Group assignment process

To ensure the comparability of the control and intervention groups, strict parameters for recruitment and subsequent group assignment using computer-controlled processes were applied before the intervention began. Participants remained blind to the conditions of the intervention - both the training and active control groups moved in the Star Craft II environment. The experimenters remained blind at two stages: group assignment and study supervision. Group assignment was conducted after initial cognitive/neural measurements and introduction to the Star Craft II game.

Twenty-nine subjects were placed in the training groups, with **15 subjects** (mean age 28.2) **in the VEG** group and **14 subjects** (mean age = 27.78) **in the FEG** group. Participants in the training groups performed approximately 60 h (± 3 h) of StarCraft 2 training each and completed the measurements at the fourth time points (T0, T1, T2 and T3).

5.1.2.d. Double-Blind Procedure

Using a computer application, participants were assigned a random ID number (501, 502... 564-glab), and the conditional label associated with the ID was not available until all data were collected. Supervision of the study was largely supervised by computer. The online platform reported training progress (number of hours of training, frequency of training, etc.) and provided participants with information about the settings they needed to use in the game.

Figure 8. Information on the platform (GEX) used to control the study: left: on training progress (number of training hours, frequency of training, etc.) and right: on the settings that the participant needs to apply in the game.

Despite the preparation, human experimenter intervention was needed in case of technical problems. Since providing such assistance posed a risk of revealing the conditions of the study, the laboratory staff responsible for supervising the training were not involved in the collection of cognitive/neural data or the operation of the initial Star Craft II tutorial.

5.2. Research Materials

5.2.1. Star Craft II as a Research Environment

Several factors contributed to the decisions, regarding the training environment, based on Plasticity Team's previous experience, as well as the observations of other researchers. Preliminary results from an earlier project conducted by the GamesLab Team (then still the Plasticity Team) on Star Craft II indicated that people without video game experience who were trained in Star Craft II showed significant improvements in visual working memory and attentional functioning compared to an untrained control population. The positive effects of training on cognitive functioning in studies using Star Craft II have also been observed by other researchers (Glass, Maddox, & Love, 2013). Moreover, Star Craft II itself has already been recognized as an optimal platform for studying the acquisition of complex skills, as detailed by Thomson (Thompson et al. 2013), emphasizing that it is a rich, dynamic task environment, designed for entertainment (which influences the motivation of players), which provides accurate measurements of motor performance and attentional allocation, and multiple levels of experience, but also the ability to modify game parameters to provide different types of training experiences.

Star Craft II's telemetric potential allows individual player activities to be extracted from recordings and quantified as performance indicators, making it possible to link cognitive/structural changes to in-game behavior. Star Craft II was chosen by DeepMind - one of the leaders in AI research at the time - as a test environment for AI research because it "provides a useful bridge to the clutter of the real world" and because the skills required for "an agent of progress in Star Craft II can eventually transfer to real-world tasks." The team members' experience in training using Star Craft II was also an argument in choosing the training environment. It allowed them to assume that the training process, including the initial training in the basic skills of the game and the tracking and compilation of training data, would be carried out according to the highest methodological standards.

By training participants in such a complex task, which was capable of generating broad cognitive benefits, it is possible to look at the potential for far-reaching transfer of training gains.

Based on the above rationale, Star Craft II was found to be an appropriate environment, providing the conditions necessary to effectively stimulate and measure the cognitive changes resulting from learning and mastering a complex, ecologically sound skill.

5.2.2. Star Craft II game telemetry data

The recorded telemetry data from Star Craft II allows us to extract a variety of game indicators. There are over 40 described indicators characterizing different aspects of game - some already described in publications on game telemetry (Thomson 2013, Jakubowska et al. 2021). These include game indicators (player decisions), as well as psychophysical data (e.g. what he did just before the game), game situation (e.g. decisions of the other player, game circumstances), for example: player type, match result, action per minute (APM), match length, match map name, hotkeys unit variability, first supply event time, first attack move time, total army units, perception action cycle (PAC), PACs action latency, PACs per minute, difficulty level, etc.

For the purpose of this study, six telemetry indicators were extracted. The following variables were chosen due to promising results from earlier research in this area (Jakubowska 2020, Lewandowska 2022 etc.).

Actions per minute (APM) is the average number of actions performed per minute in the game - a measure of cognitive motor speed. It is an automatically calculated variable by the game often used as a predictor of expertise in the StarCraft community. It can be interpreted as cognitive, motor and decision-making speed. It is the most popular variable indicating a player's level. The APM of experienced players reaches about 267, while inexperienced players reach about 60, indicating a process of skill learning.

The **hotkeys** variable is the average number of hotkeys pressed per minute in each game, where each action represents the automatic selection of multiple units or buildings.
The choice of this variable was based on its importance to players. It allows you to switch between tasks more quickly and therefore play in a more efficient way. The use of hotkeys is necessary to significantly improve performance, especially for novice players. Players can customize the interface to select and control their units or buildings faster, thus relieving the game interface of some of the aspects of manually clicking on specific units. Once a set of

units is assigned to a hotkey, players can select those units at any time to give them orders. The value of this variable refers to the number of these choices per minute

Perception-Action-Cycle Variables - Variables that refer to the time interval during which players fixate and act at a specific location. Many of these variables will therefore reflect several processes: both attentional processes - because PACs have consequences for what players are able to pay attention to, perceptual processes - because screen shifts imply new stimuli and cognitive-motor speed - actions must not only be fast, but also meaningful and useful. PAC is the mean number of actions within a PAC (1 is the smallest value).

PAC Action Latency is the average delay from the start of a PAC to the first action taken in that PAC, measured in seconds of real time. One PAC begins with an attention switch and ends with another attention switch. While participants' first matches are played in only one observed region (PAC = 1), as they gain experience in the game, participants are able to quickly switch between multiple remote and independent locations on the map.

The **First Attack Move Time** can provide valuable information about a player's decision-making and strategic abilities in the game. For example, a shorter first attack move time may indicate a player who is more aggressive and takes quick action in the game. On the other hand, a longer first attack move time may suggest a more cautious or defensive playing style. Furthermore, analyzing the first attack move time can help identify patterns in a player's behavior, such as if they tend to use the same tactics or strategies repeatedly, or if they adapt their approach based on the circumstances of the game.

The **Total Army Units** telemetric variable provides valuable information about a player's military strength in the game. This information can be used to determine whether a player is focused on building up a strong offensive or defensive force, and whether they are likely to be successful in battles against opponents with a lower number of army units. Additionally, analyzing the total army units variable over time can provide insight into a player's overall strategy and decision-making in the game. For example, a sudden increase in the number of army units may indicate that a player is preparing for an offensive attack, while a decrease in army units may suggest that they are trying to conserve resources or retreat from a battle.

The selected telemetry variables are characterized by a low starting score due to zero game experience, and a regular increase with subsequent matches played.

The telemetry variables were extracted from Star Craft II game replays, using Star Craft IIreader (downloaded from https://github.com/ggtracker/Star Craft IIreader) and PACanalyzer (downloaded from https:// github.com/Reithan/PACAnalyzer), which are

Python libraries for extracting information from various Star Craft II resources. These libraries made it possible to extract replay details, such as information about the map used, match length, game type, etc. but also more detailed data, regarding player behavior, such as: unit selection events and hotkeys, resource transfers and requests, unfiltered unit commands (attack, move, train, build, etc.). During the study, a total of **5664 repetitions of Star Craft II (M = 195.31, SD = 41.28) were collected from 29 participants.** After initial extraction, matches that lasted longer than XX minutes or shorter than 1 minute were filtered out, assuming they were the result of computer or user error (e.g., starting a match of the wrong type). The average match lengths for each participant were then calculated. Another filter cut out matches longer and shorter than the average length of matches played ± 1 standard deviation. Game fitness depended on a number of variables, but for the purposes of the study, the focus was on variables that were fundamental, yet sensitive to the player's skill development (Thompson et al., 2017).

5.2.3. Playing Conditions in Two Groups

Subjects began Star Craft II training proper, divided into two groups: Variable Environment Group (VEG) and Fixed Environment Group (FEG). This approach follows the proposal of Glass et al. (2013), in which the authors created two training conditions, assuming that a less predictable and repetitive training experience would lead to a slower rate of automation of game behavior, and thus provide greater overall task demands over the training period. Participants underwent Star Craft II game sessions under controlled laboratory conditions with the prohibition of playing outside the laboratory. The Star Craft II training in the study presented here consisted of 60 h, lasting approximately 6 weeks, with a maximum of 5 hours per day. Both groups played 60 hours as the Terran faction, with the FEG group always playing against the Terran faction using the "Economic Focus" strategy. However, in the VEG group, opponents were randomly chosen from three races, and strategies were selected from five different strategies. Participants from the VEG group changed their opponent from AI to human after 30 hours. The difficulty of the game was varied at 8 levels (Match Map Level: very low, low, medium, high, higher, very high, elite, cheater).

The online platform software recorded the number of losses (-1) and wins (+ 1), and the difficulty was increased by one each time the total exceeded a threshold multiple of 4.

When the total fell below the threshold, the difficulty decreased. The training was carried out using dedicated desktop computers with Windows 7 operating system (professional edition, 64-bit) equipped with a dedicated graphics card (NVIDIA GeForceGTX 770), 8 GB of RAM and a 24′LED display that allowed the game to be played in high graphic quality (1920 × 1080 pixels resolution, 60 Hz). Participants played the game using a mouse, keyboard and headset.

5.2.4. Questionnaires

The study used questionnaires with which players' characteristics: **personality, dispositional flow** and **intelligence** were examined.

5.2.4.a. Players' Characteristics

The **NEO-FFI** (NEO Five-Factor Inventory) questionnaire is a widely used personality assessment tool based on the Five-Factor Model (FFM) of personality. It measures five primary dimensions of personality known as the Big Five traits: Neuroticism, Extraversion, Openness to Experience, Agreeableness, and Conscientiousness.

The NEO-FFI questionnaire consists of 60 items, with each trait being assessed by 12 items. Respondents are required to rate their level of agreement or disagreement with statements that describe various aspects of their personality. The questionnaire typically uses a Likert-type scale, where respondents indicate their agreement on a scale ranging from strongly disagree to strongly agree.

Here is a brief description of each of the five factors measured by the NEO-FFI questionnaire:

1. Neuroticism measures emotional stability versus instability. Individuals high in neuroticism tend to experience negative emotions more frequently and intensely, while those low in neuroticism are more emotionally resilient.
2. Extraversion assesses the extent to which individuals are outgoing and sociable. High extraversion scores indicate a preference for social interaction, assertiveness, and positive emotions, while low scores suggest introversion and a preference for solitude.
3. Openness to Experience measures a person's receptiveness to new ideas, creativity, and willingness to explore unconventional experiences. High openness scores indicate

curiosity, imagination, and a broad range of interests, while low scores suggest a preference for tradition and familiarity.

4. Agreeableness reflects how individuals relate to others and their tendency to be cooperative, compassionate, and trusting. High agreeableness scores indicate empathy, friendliness, and a cooperative nature, while low scores suggest a more competitive and skeptical orientation.
5. Conscientiousness measures the degree to which individuals are organized, responsible, and goal-oriented. High conscientiousness scores indicate self-discipline, reliability, and a preference for planning and organization, while low scores suggest a more spontaneous and flexible approach.

The NEO-FFI questionnaire provides a comprehensive assessment of an individual's personality traits, offering insights into their emotional tendencies, social behavior, openness to new experiences, interpersonal style, and conscientiousness. It is commonly used in research, clinical settings, and personality assessments for various purposes, including psychological profiling, counseling, and career development.

Raven's Matrix is a tool in measuring abstract reasoning and cognitive abilities. It is a non-verbal intelligence test designed to measure abstract reasoning and problem-solving abilities. It consists of a series of matrices or patterns, with one missing piece, and the task is to identify the missing piece from a set of options.

The matrices are structured in a progressive manner, increasing in difficulty as the test progresses. The missing piece in each matrix follows a specific pattern or rule, and the test taker must discern the underlying logic or pattern to select the correct answer.

The test provides a standardized score, allowing for comparisons between individuals and populations. It is used for various purposes, such as identifying intellectual giftedness, assessing cognitive decline or impairment, and evaluating problem-solving skills in job selection processes.

PDFS-2 (Polish version of Dispositional Flow Scale - 2) was described in the section on Study I.

5.2.4.b. Non-Telemetric Measurements During Training

During 60 hours of training, players went through flow (PFSS-2) and mental workload (NASA Task Load Index - NASA TLI) measurements ca. 11 times. The basic element of the study was one session, a period starting from the first game of Star Craft II from the previous measurement to the next measurement. The average time of 1 session is about 5.45 (60 h/11 = 5.45). The number of games played during a session was dependent on the player's performance.

The **NASA Task Load Index** (Stanton et al., 2005, NASA TLX, 2006) is a tool for measuring and conducting subjective assessments of mental workload (MWL). It enables a participant's MWL to be determined while performing a task. It assesses performance along six dimensions:

Mental demand	how much thinking, deciding or calculating was required to complete the task
Physical demand	the amount and intensity of physical activity required to perform the task
Time demand	the level of time pressure involved in completing the task
Effort	how hard the participant must work to maintain his or her level of performance
Performance	the level of success in completing the task
Frustration	how insecure, discouraged, secure or satisfied the participant felt while completing the task

Each subscale is presented to participants during or after the experimental trial. Participants are asked to rate their score on an interval scale from low (1) to high (20).
The subscales are presented to participants either during or after the experimental trial. Participants self-assess on a scale from 1 (low) to 20 (high), using 15 pairwise combinations designed to elicit from participants the pair that has the greatest impact on workload during the task. PFSS-2 (Polish version of Flow State Scale - 2) was described in the Methology section of Study I.

5.2.45. Cognitive Tasks

The last group of tools,used in the study were cognitive tasks: Memory Updating, Task Switching, VMDD and Stop Signal.

5.2.4.a. Memory Updating

Memory Updating refers to the process of modifying and integrating new information into existing memory representations. It involves the ability to discard outdated or incorrect information and incorporate relevant details. This cognitive process is crucial for learning, problem solving and adapting to new situations. Effective memory updating allows us to continuously improve our understanding of the world and make informed decisions based on the most current information available.

The screen presented a square divided into four 2 × 2 boxes (10 degrees wide/height) on a gray background. Each box displayed digits from 0 to 9, which appeared sequentially in pseudo-random spatial order in each cell of the matrix for 1 sec. In the next phase, new digits began to appear in pseudo-random locations, depending on the load condition. This update could occur from 0 to 5 times in a trial, with the same cell being updated only twice in the case of a load of "5". After the update, a single cell was probed at random. The participant's task was to remember the initial values that appeared in the first phase, and then update the value of each cell if a new digit appeared in it, using simple addition/subtraction. The value of each update was chosen pseudorandomly, although the update could never be 0 and could not cause the cell's value to fall below 0 or exceed 9. Participants responded to the probe by entering the value they last assigned to the cell under study.

Indicators of Task Performance

Six training trials (sequentially increasing load) and three blocks of 30 trials were performed. The load was evenly distributed and varied in each block. Accuracy of response was the main measure of this procedure. The task lasted about 20 minutes and consisted of a training portion and the actual task. While the subject was informed of the correctness of the decision during training, such information was not given during the actual task.

5.2.4.b. Task Switching

Task Switching is a procedure based on the approach used by Colzato et al. (2012), with target stimuli adapted from Huizinga, Dolan and van der Molen (2006). The key element here was to verify the dynamics of the cost incurred by the subject when switching from task to task. Each subject completed the task four times, going through the same process each time. Participants were required to respond to large (global) or small (local) geometric figures depending on the cue presented. Global figures consisted of local figures. Three blocks of trials were conducted in each measurement block: two training blocks of 30 trials each, in which response instructions were constant across trials (global only and local only), and one experimental block of 176 trials, in which participants switched between global and local trials in sequences of every 4 trials.

The task lasted 15 minutes each time. The subject, depending on the condition, was asked either to indicate what the figure consisted of (at the top of the screen) or the overall shape of the figure presented (at the bottom of the screen). The questions indicated which dimension (global or local) participants should answer. The cues relating to the global (local) dimension consisted of a large (small) square, placed on one side of the target stimulus, and a large (small) rectangle, presented on the other side of the target stimulus. The color of the cues and target was red. Both remained on the screen until a response was made or 2500 ms elapsed. The interval between the presentation of the cue and the target stimulus ranged from 400 to 500 ms, and the interval between the response and the next presentation of the cue ranged from 900 to 1100 ms.

The experiment was controlled by a computer connected to a 17-inch monitor with a refresh rate of 100 Hz. Responses were made by pressing "Z" or "M" on a QWERTY computer keyboard with the left and right index fingers, respectively. The target stimuli were adapted from the work of Colzato et al. (2010) and consisted of geometric figures. Larger (global) rectangles/squares consisted of smaller (local) rectangles or squares. Global stimuli (i.e., squares or rectangles, 93 9 93 or 41 9 189 pixels, respectively) were composed of multiple smaller "local" stimuli (i.e., squares or rectangles, 21 9 21 or 8 9 46 pixels, respectively). The space between the local stimulus elements was 3 pixels. A global square consisted of 16 small squares or 16 small rectangles, a global rectangle consisted of 16 small squares or 16 small rectangles. The "local" and "global" cues were the same size as the global and local stimuli and were presented at a distance of 189 pixels from the center of the computer screen.

Participants responded to randomly presented rectangles or squares by pressing the left or right response button, respectively.

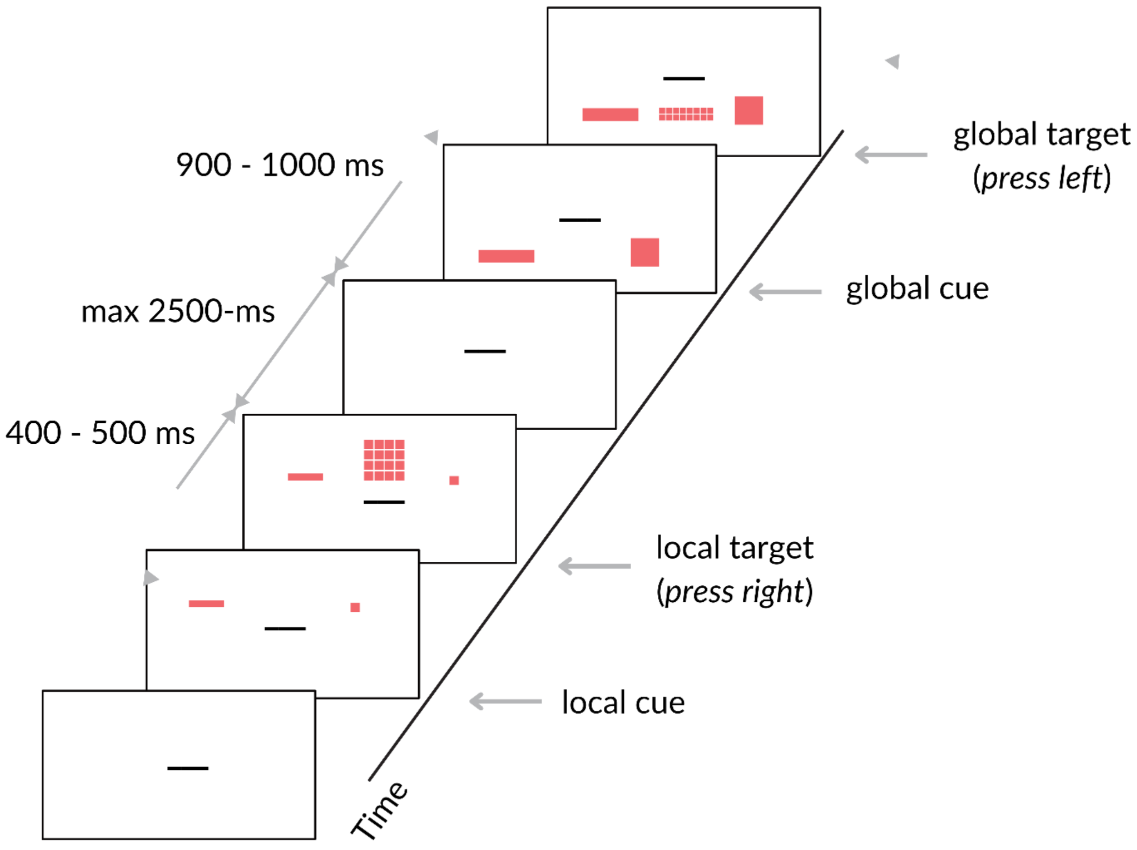


Figure 9. Illustration of the sequence of events in a trial of the switch blocks

Indicators of Task Performance

In the cost analyses, the data, regarding the response time of the subject, were included:

a. averages from all trials, separately in each mode: global and local

b. averages from a sequence of 4 trials, separately in each mode: global and local

c. differences in reaction time between the trial closing the global or local sequence and opening the altered global or local sequence

d. differences in response time between the sum of the global or local sequence and the trial opening the changed global or local sequence.

The Task Switching vs. flow correlation analysis included data collected from 29 individuals of the VEG and FEG, i.e., those who participated in training and underwent flow measurements during the game.

5.2.4.c. Visual Motion Direction Discrimination (VMDD)

In VMDD analogous to the procedures used by Britten et al. (1992), Palmer et al. (2005) and Shadlen and Newsome (2001), each trial began with the presentation of a red fixation circle (0.4 degrees in diameter) in the center of a 5-degree diameter hole (light gray background) for 1000 ms. This was followed by a motion display in which dots (0.1-degree squares) moved across the screen at a rate of about 5 degrees per second, with a density of 16.7 dots per square degree per second. In this motion display, the dots either moved continuously or coherently to the left or right side of the aperture. Five levels of motion coherence (percentage of dots moving in coherence) were used: 1,6%, 3,2%, 6,4%, 12,8% i 25,6%. Participants were asked to indicate the direction in which the coherent dots moved (evenly divided between trials). The display of movement lasted for 2 s or until an answer was given. The fixation wheel then changed color for 1000 ms to indicate the answer as correct/correct/interrupted: green (if the answer was correct), yellow (if the answer came too late), red (if the answer was wrong).

Indicators of Task Performance

Participants performed 10 training trials at each coherence level, followed by 75 trials at each coherence level, for a total of 425 trials. The primary measures for this task were response accuracy and reaction time for each level of coherence.

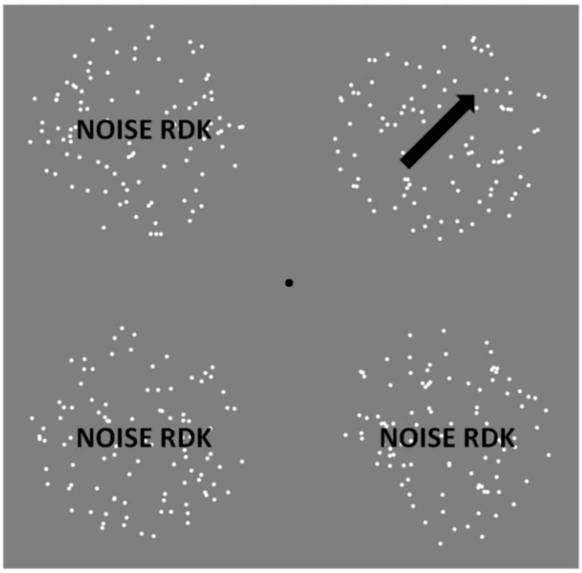


Figure 10. Stimulus used in the VMDD experiment. In the experiment described by Pavan et al. (2016), the researchers used a stimulus called a Random Dot Kinematogram (RDK). An RDK consists of a display containing multiple dots randomly scattered across the screen. These dots can move independently of each other, creating the perception of motion. Only

one RDK contained consistent global motion (the upper right RDK moving at 45 degrees in the example), while the other spots were noise RDKs. (Pavan et al., 2016)

5.2.4.d. Stop Signal

The Stop Signal Task, based on the work of Logan and Cowan (1984), is a test of prepotent response inhibition, a key feature of executive control. According to the specifications outlined by Verbruggen et al. (2008), each trial began with an initial fixation cross (2 degrees in size) presented against a gray background, which lasted 250 ms. This was followed by the main task stimulus, which could be a white circle (10 degrees in diameter) or a white square (10 × 10 degrees) that remained on the screen for 1,250 ms or until a response was given. Participants were asked to identify the shape of the target stimulus as quickly as possible. On some paths, the target shape may have changed color from white to red shortly after it was initially sent (stop trials). Participants were to inhibit their response on trials in which the target changed color by indicating their choice as quickly and accurately as possible by pressing the "D" key for the left-facing arrow and the index finger of the right hand on the "L" key for the right-facing arrow.

The task had a stepped design for the stop signal delay (SSD), which allowed it to be adjusted according to the participant's performance. In the initial block of 120 trials, participants were required to respond to the target as quickly as possible. This allowed the calculation of reaction times for trials for each participant and indicated the reaction speed expected during subsequent stop signal trials. For the experimental trials, in 25% of the trials the arrow was then replaced by an audible stop signal (see Fig. 8), indicating that the response should be paused. The delay between target presentation and color change (stop signal delay, SSD) was initially 250 ms. Any response made when the stop signal appeared was scored as an error, while successfully pausing the keystroke was scored as a correct response. Correct responses resulted in a 50 ms increase in the time of the next stop signal, making the next trial with a stop signal more difficult, while an error resulted in a 50 ms decrease in time, making it easier to withhold a response on the next trial with a stop signal. Each trial in which an answer fell outside this limit was scored as an error, which was intended to discourage participants from strategically slowing down their answers. As Chen and Muggleton (2020) write, this behavior can occur when participants delay their responses to see if a stop signal will be presented (Chen et al., 2008). Participants initially completed 32 training trials, followed by three blocks of 64 trials, 25% of the trials in each block were stop trials, and the SSD value was carried across all blocks. SSD was the main measure in this procedure. The task lasted about 15 minutes.

Following the indications from the literature (Friehs et al. 2020) in the data reduction phase, participants were excluded if they did not cooperate or presented erroneous data. Outliers were then identified based on Tukey's (1977) criterion within the data and removed if necessary. After these procedures, 3 participants were excluded, yielding a sample of 26 individuals with valid behavioral data.

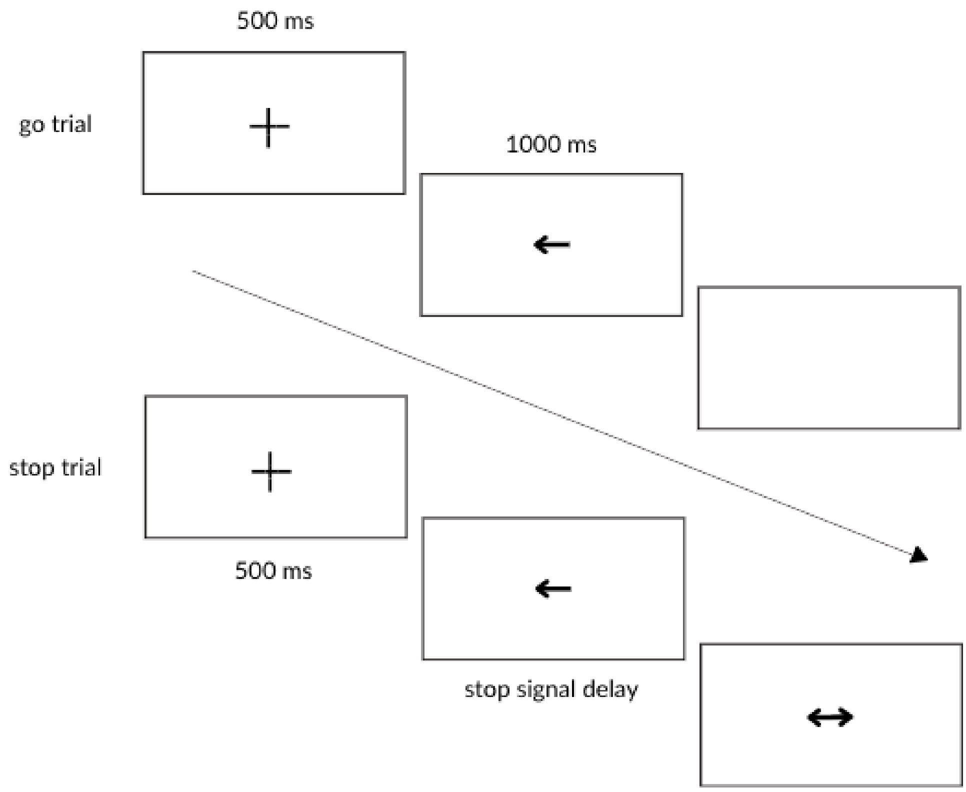


Figure 11. A run-through of the stop-signal task. For go trials, which accounted for 75% of the trials presented, an initial fixation was presented for 500 ms, followed by an arrow pointing either left or right. Both directions appeared equally often and in random order. Participants were required to indicate the direction of the presented arrow with a keystroke and do so both quickly and accurately, and within a time limit of 1000 ms. In the remaining 25% of trials, a stop signal was presented after the arrow was presented, indicating that the response should be paused. The timing of the stop signal was varied for each person depending on the accuracy of their performance on the stop trials.

Indicators of Task Performance

The primary measure of SST performance was SSRT - stop signal response time - the number of milliseconds of warning a participant needs to successfully stop a planned response. SSRT estimation was based on the integration method with skip substitution. SSD, or Stop Signal Delay, was also measured.

5.2.5. Study Objectives, Research Questions and Hypotheses

In this study the main goal was to investigate what is the role of player's flow in learning complex skills during the Star Craft II game, implemented with reference to 3 specific goals:

1. the relationship between the level of flow achieved by a player during training with an RTS game and the results obtained in the game
2. identification of the player's predispositions, which can be behavioral and mental predictors of flow level
3. the relationship between the level of flow a player achieves during training with an RTS game and the results obtained in a cognitive task

The number one goal is to test whether a player's level of flow is related to his performance in the real-time strategy game (RTS) process as measured by telemetry variables. The realization of the goal - within the framework of the presented study - will be possible by answering the following research questions and the hypotheses set in relation to them:

No	Research Question	Hypothesis
1.	**Will a player's level of flow be related to his RTS game performance measured by telemetric variables?**	**H.1 Player's level of flow is related to his RTS game performance measured by telemetric variables.**
1.	Is there a relationship between **match results** and perceived flow state?	**H.1.1.a** Perceived flow state is positively correlated with the score of the last game before measurement. (Variables: Mean Match Result in Total, Mean Flow State) **H.1.1.b** Perceived flow state in a session is positively correlated with the average game score. (Variables: Mean

		Match Results by Measurement Point, Mean Match Result in the Last Session, Mean Flow State) **H.1.1.c** Perceived flow state is positively correlated with the score of the last game before measurement. (Variables: Last Match Result In the Last Session, Mean Flow State)
2.	Is there a correlation between the perceived flow **state** and **gameplay time**?	**H.1.2.a** Perceived flow state in a session is positively correlated with the average time of individual games in a session. (Variables: Mean Training Time in Session, Mean Flow State) **H.1.2.b** Perceived flow state in a session is positively correlated with the amount of time elapsed since the previous game day. (Variables: Time Since Last Session, Flow State) **H.1.2.c** Perceived flow state in a session is positively correlated with the amount of total play time preceding the measurement on a given day. (Variables: Session Time, Flow State) **H.1.2.d** Perceived flow in a session is positively correlated with the amount of time left for the participant to complete the study, especially after the penultimate measurement. (Variables: Time to the Training End, Flow State)
3.	Is there a relationship between the perceived **flow state** and the **difficulty level of the game**?	**H.1.3.** Perceived flow state in a session is positively correlated with the difficulty level? (Variables: Match Map Level, Mean Flow State)
4	Is there a relationship between players' perceived **flow state** and their **in-game proficiency?**	**H.1.4.a** Perceived Flow State positively correlates with telemetry data (APM, Hotkeys, PACsPerMinute) session by session (N = 261) and negatively with PACsActionLatency. **H.1.4.b** Perceived Flow State correlates with telemetry data in the two snapshots: last and first match before/after flow measurement. Positively correlates with **average actions per minute** (APM), **average number of hotkeys pressed per minute (**Hotkeys), **perception action cycle per minute (**PACsPerMinute) and negatively with the **average delay from the beginning of the perception action cycle to the first action taken in that PAC** (PACsActionLatency). **H.1.4.c** Perceived Flow State is positively correlated with averaged telemetry scores between groups, separated based on individual differences in tendency to experience high/low flow. **(**APM, Hotkeys, PACs, FirstArmy, PFSS-2)

Specific objective #2 is to determine whether identifying player predispositions may be behavioral and mental predictors of flow level.

No	Research question	Hypothesis
	2. Are there mental predictors that can identify a player's predisposition to achieve a higher level of flow?	H.2 **There are behavioral and neurophysiological predictors that can identify a player's predisposition to achieve a higher level of flow.**
1.	Does the **level of susceptibility to flow** relate to **flow** level when learning complex skills during the game?	**H.2.1** Flow as a trait is positively correlated with ratings of flow state during the learning process. The higher the baseline flow, the higher the susceptibility to flow as a state. (PDFS-2, PFSS-2)
2.	Is there a relationship between **flow** and a player's **personality** traits?	**H.2.2.a** Flow is correlated with **personality traits** (NEO FFI, PFSS-2) **H.2.2.b** Neuroticism and agreeableness affect a player's performance (PACs per Minute) in a game through mediation by flow or its dimensions
3.	Is there a relationship between **flow** and a player's level of **intelligence**?	**H.2.3** Flow is not correlated with ratings of flow state during the learning process. (Raven Matrix, PFSS-2)
4.	Is there a relationship between **flow** and a **sense of task load** during the learning process?	**H.2.4** Flow is negatively correlated with the dynamics of sense of task load during the learning process. (NASA TLX, PFSS-2)

Specific objective #3 is to determine whether the results obtained in cognitive tasks are related to the level of flow a player achieves during training with an real-time strategy game.

No	Research Question	Hypothesis
	3. Will the level of flow a player achieves during training with an RTS game be related to the change in cognitive tasks after training?	**H.3 Results obtained in cognitive tasks are related to the level of flow a player achieves during training with an real-time strategy game.**

1.	**Do the dynamics of accuracy in memory updating task in the process of learning complex skills differ depending on the player's perceived level of flow?**	**H.3.1.a** Accuracy in memory updating task during the learning process of a complex skill varies according to the average flow level the participant reported when measured during the game. (Memory Updating, PFSS-2) **H.3.1.b** The level of accuracy in memory updating task during the learning process of a complex skill varies - in each flow dimension - depending on the level the participant recorded in a given dimension when measured during the game. (Memory Updating, PFSS-2)
2.	**Do the dynamics of the cost of switching a player's attention during the process of learning complex skills vary according to the player's perceived level of flow?**	**H.3.2.a** The cost of switching attention during the process of learning a complex skill varies according to the mean level of flow the participant reported when measured during the game. **H.3.2.b** The cost of switching attention during the learning process of a complex skill varies - in each flow dimension - depending on the level the participant reported in a given dimension when measured during the game.
3.	**Do the dynamics of a player's accuracy and reaction time in VMDD task during the process of learning complex skills differ depending on the player's perceived level of flow?**	**H.3.3.a** The accuracy and reaction time for each level of coherence during the learning process of a complex skill varies according to the mean level of flow the participant recorded during the game measurement. (Visual Motion Direction DIscrimination VMDD, PFSS-2) **H.3.3.b** The accuracy and reaction time for each level of coherence during the learning process of a complex skill varies according to level of each from flow dimensions, the participant recorded during the game measurement. (VMDD, PFSS-2)
4	**Do the dynamics of a player's reaction inhibition during the process of learning complex skills differ depending on the player's perceived level of flow?**	**H.3.4.a** The accuracy and signal inhibition response time during the learning process of a complex skill varies depending on the average level of flow that the participant reported during the game measurement. (Stop Signal, PFSS-2) **H.3.4.b** The accuracy and signal inhibition response time during the learning process of a complex skill varies - in each flow dimension - depending on the level the participant recorded in a given dimension when measured during the game. (Stop Signal, PFSS-2)

5.2.6. Data Analysis

In response to the research questions, various statistical methods were used in the data analysis to examine the relationships between the variables. A summary with a list of variables and methods of analysis used in the study can be found in Table 19.

Table 19. List of variables and methods of analysis used in the study

Research Question	Variables	Method of Analysis
1. Will a player's level of flow be related to his RTS game performance measured by telemetric variables?	Mean Flow State, dimensions of flow (Challenge-Skill Balance, Merging of Action and Awareness, Clear Goals, Unambiguous Feedback, Concentration on the Task at Hand, Sense of Control, Loss of Self-Consciousness, Transformation of Time, Autotelic Experience), Mean Training Time in Session, Mean Match Result, Mean Match Results until Measurement Point, Mean Match Result Since the Last Session, Last Match Result, FlowProxyCsik, FlowExpCsik, FlowProxyStav, FlowExpStav	● Spearman's rank correlation analysis, ● Pearson's r correlation analysis, ● Student's t test for dependent samples
	Mean Flow State, dimensions of flow, Mean Training Time in Session, Time Since Last Session, Session Time, Time to Training End	● Pearson's r correlation analysis,
	Mean Flow State, dimensions of flow, FlowProxyCsik, FlowExpCsik, FlowProxyStav, FlowExpStav, Match Map Level	● Spearman's rho correlation analysis
	Mean Flow State, dimensions of flow, Match Won, Match Played, Average Action per minute APM, Hotkeys Total, First Attack Move Time, Total Army Units, PACs Per Minute and PACs Action Latency, FlowProxyCsik, FlowExpCsik, FlowProxyStav, FlowExpStav	● Spearman's rho correlation analysis

2. Will a player's level of flow be related to his RTS game performance measured by telemetric variables?	Mean Flow State, Dispositional Flow Mean, dimensions of flow and dispositional flow	● Student's t test for dependent samples, ● Pearson correlation analysis
	Mean Flow State, NEO FFI (Neuroticism, Extraversion, Openness for experience, Agreeableness, Consciousness), PACs per Minute	● multivariable regression analysis (predictor: NEO FFI; dependent variable: Mean Flow State and its dimensions), ● mediation analyses (predictor: NEO FFI; dependent variable: PACs per Minute, mediator: Mean Flow State and its dimensions)
	Mean Flow, dimensions of flow, Intelligence Level	● Spearman correlation analysis
	Mean Flow, dimensions of flow, NASA TLX (Mental, Physical, Temporal, Effort, Frustration, Performance)	● multivariable regression analysis (predictor: NASA TLI; dependent variable: Mean Flow State and its dimensions)
3. Will the level of flow a player achieves during training with an RTS game be related to the change in cognitive tasks after training?	Mean Flow State, flow dimensions, Accuracy (MU), Switching Cost, Accuracy (VMDD), Reaction Time (VMDD), Stop Signal Delay (SSD)	● ANOVA analyses, where: measurement (4) as a within-subject factor and group (VEG, FEG) and flow level (high or low)

5.3. Results

5.3.1. Will a player's level of flow state be related to his real-time strategy (RTS) game performance measured by telemetric variables?

Specific objective No. 1 was to verify if a player's flow level is related to his performance in an real-time strategy (RTS) game, measured by telemetry variables.

This chapter presents the results of the analysis in the search for an answer to the question of whether there is a relationship between flow and how a person behaves in the process of playing StarCraft 2. To analyze the results, the following variables were used:

- relationship between **match results** and perceived **flow state**: Mean Match Result, Mean Match Results by Measurement Point, Mean Match Result in the Last Session, Last Match Result In Last Session
- relationship between **time** and perceived **flow state**: Mean Training Time in Session, Time Since Last Session, Session Time, Time to Training End
- relationship between **difficulty level** and perceived **flow state**: Match Map Level
- relationship between players' perceived **flow** state and their **in-game proficiency**: Action per Minute/APM, Hotkeys, PACsPerMinute, PACsActionLatency

1. **Is there a relationship between match results and perceived flow state?**

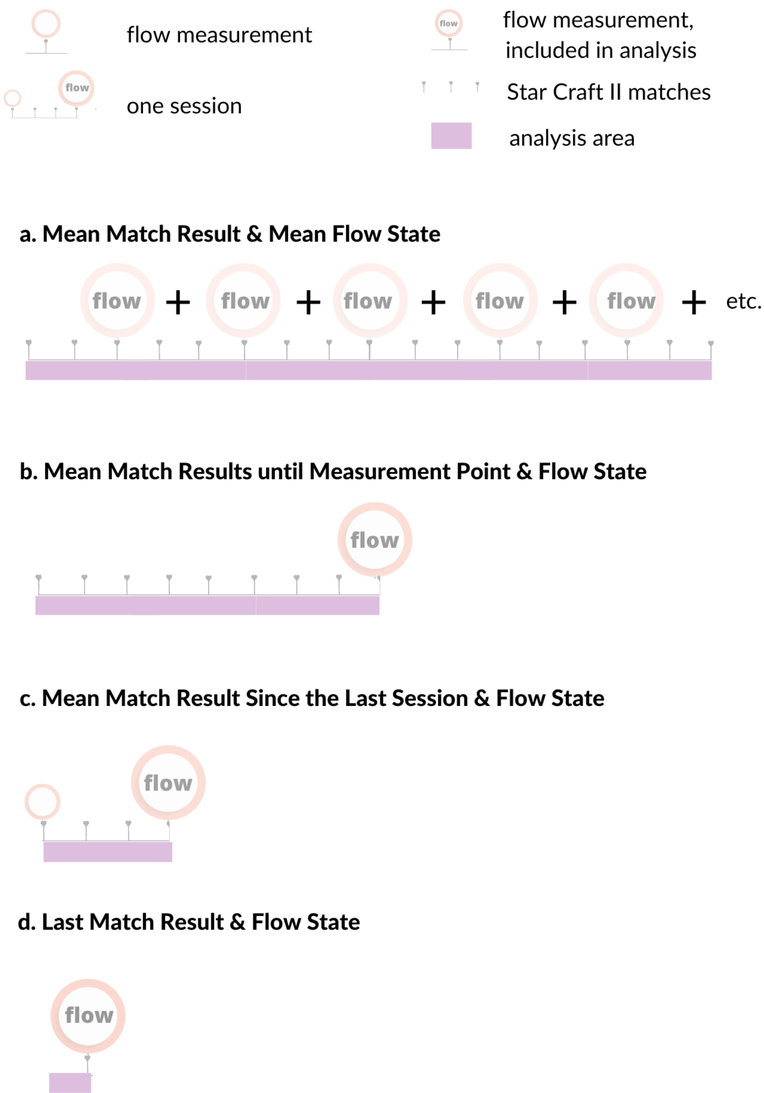


Figure 12. Illustration of variables created to verify the relationship between match results and perceived flow state

H.1.1.a Perceived flow state is positively correlated with the **Mean Match Result**. (Mean Match Result, Mean Flow State)

The first step (Fig. 12 a) was to verify whether there is a relationship between Mean Match Result understood as a win-loss relationship (1 - 0) and Flow State in the traditional flow approach Csikszentmihalyi (2000). Spearman's rank correlation analysis showed moderate positive correlations between variable Mean Match Results and Flow State (rho = 0.310, p = <0.001).

The relationship between flow condition and match outcome was then examined in two theoretical flow models: based on the traditional theory of Csikszentmihalyi (2000) and Stavrou and Zervas (2004). The difference between the models is described in more detail on page 27. In both models, the proximal and experimental components of flow were separated. For this purpose, proximal and experimental variables were created: FlowCsikProxy and FlowCsikExp - for the **model of Csikszentmihalyi** and FlowStavProxy and FlowStavExp for the **model of Stavrou and Zervas** as indicated by theoretical models.

Table 20. Correlations between Match Result and flow - in traditional terms and according to models: a. Csikszentmihalyi and b. Stavrou and Zervas

N=308		FlowCsikProxy	FlowCsikExp	FlowStavProxy	FlowStavExp	Flow State
Match Result	rho Spearman	**0,160**	**0.189**	**0.183**	**0,160**	**0,31**
	significance	0.005	<0.001	0.001	0.005	<0,001

Spearman's rank correlation analysis showed weak positive correlations between variable **Match Result** and the following variables: **FlowCsikProxy** (rho = 0.160, p = 0.005), **FlowStavProxy** (rho = 0.183, p = 0.001), **FlowCsikExp** (rho = 0.160, p = 0.005), and **FlowStavExp** (rho = 0.189, p < 0.001). The degrees of freedom (df) for the analysis was 306).

H.1.1.b Perceived flow state in a session is positively correlated with the average game score. (Mean Match Results until Measurement Point, Mean Match Result in the Last Session, Flow State Scale)

Next, it was checked whether there was a correlation between the a. average score of all games played up to the time of filling out the form (Fig. 12 b.) and b. the average score of the last session and the flow rating (Fig. 12 c.). For this purpose, Pearson's r correlation analysis was performed, the results of which are presented in Table 21.

Table 21. Correlation of the average score of the games and the flow level assessment

			Mean Match Results by Measurement Point	Mean Match Result Since Last Session
Flow State Scale		Pearson's r	**0,31**	**0,35**
		significance	<0,001	<0,001
1	Challenge-Skill Balance (1)	Pearson's r	**0,31**	**0,36**
		significance	<0,001	<0,001
2	Merging of Action and Awarness (2)	Pearson's r	**0,19**	**0,28**
		significance	<0,001	<0,001
3	Clear goals (3)	Pearson's r	**0,26**	**0,33**
		significance	<0,001	<0,001
4	Unambiguous feedback (4)	Pearson's r	**0,24**	**0,27**
		significance	<0,001	<0,001
5	Concentration on the Task at Hand (5)	Pearson's r	**0,20**	**0,17**
		significance	<0,001	0,003
6	Sense of control (6)	Pearson's r	**0,34**	**0,38**
		significance	<0,001	<0,001
7	Loss of Self-Consciousness (7)	Pearson's r	**0,16**	**0,14**
		significance	0,005	0,009
8	Transformation of time (8)	Pearson's r	**0,17**	**0,13**
		significance	0,002	0,022
9	Autotelic experience (9)	Pearson's r	**0,19**	**0,27**
		significance	<0,001	<0,001

The analysis showed statistically significant positive relationships between the the level of flow, in all the dimensions considered, and the **Mean Match Results by Measurement Point** and **Mean Match Result Since Last Session** (average of all matches that took place in the last session, that is, between the previous and current flow measurement). This means that as the **Mean Match Results by Measurement Point** or **Mean Match Result Since Last Session** increased, the level of **Flow State** in all the dimensions studied increased. Noteworthy, however, is the fact that most of the relationships turned out to be weak ($r < 0.3$).

H.1.1.c Perceived flow state is positively correlated with the score of the last game before measurement. (Last Match Result, Flow State)

The last step of the analysis was to see if there was a relationship between the score of the last gameplay just before filling out the form of flow state and perceived Flow State (Fig. 12 c). To do this, a Student's t test for dependent samples was used, the results of which are shown in Table 22.

Each time, the FSS-2 score was matched against the game score, and wins were compared with losses.

Table 22. Comparison of the flow level assessment according to the score obtained in the last gameplay

		Loss (*n* = 128)		**Win** (*n* = 161)				*Cohen's d*
		M	*SD*	*M*	*SD*	*t*	*p*	
Flow State Scale		117,73	21,63	128,58	19,23	-4,51	<0,001	0,53
1	Challenge-Skill Balance (1)	11,41	3,47	13,11	3,27	-4,27	<0,001	0,51
2	Merging of Action and Awareness (2)	11,77	2,82	12,75	2,90	-2,89	0,004	0,34
3	Clear goals (3)	13,65	2,92	14,93	2,68	-3,89	<0,001	0,46
4	Unambiguous feedback (4)	13,62	3,08	15,12	2,63	-4,41	<0,001	0,53
5	Concentration on the Task at Hand (5)	14,80	2,46	15,57	2,33	-2,74	0,007	0,32
6	Sense of control (6)	12,44	3,19	14,27	2,74	-5,26	<0,001	0,62
7	Loss of Self-Consciousness (7)	15,23	3,67	15,76	3,47	-1,27	0,203	0,15
8	Transformation of time (8)	13,28	4,30	13,95	4,28	-1,32	0,189	0,16
9	Autotelic experience (9)	11,54	3,79	13,11	3,68	-3,56	<0,001	0,42

The analysis showed statistically significant differences between wins and losses in the last match before completing the Flow State Scale (FSS-2) form, on all variables except Loss of Self-Consciousness (7) and Time transformation (8). It turned out that win matches were characterized by higher levels than los ones on all variables considered. In addition, it is worth noting that in the case of **Flow State, Challenge-Skill Balance (1), Unambiguous feedback (4) and Sense of control (6)**, the observed effect appeared to be moderately strong (0.5 < Cohen's d < 0.8).

In a sequential step, the relationship between perceived flow and asperities, related to time in the game training process, was analyzed.

H.1.2.a Perceived flow state in a session is positively correlated with the average time of individual games in a session. (Mean Training Time in Session, Flow State Scale)

At the beginning, it was checked whether there was a relationship between the flow level rating and average gameplay time. For this purpose, Pearson's r correlation analysis was performed. The results of the analyses are shown in Table 23.

Table 23. Correlation of flow rating and average playing time and level of gameplay sophistication

			Mean Training Time In Session
	Flow State Scale	Pearson's r	0,06
		significance	0,323
1	Challenge-Skill Balance (1)	Pearson's r	0,04
		significance	0,445
2	**Merging of Action and Awareness (2)**	Pearson's r	**-0,12**
		significance	0,037
3	Clear goals (3)	Pearson's r	0,03
		significance	0,645
4	Unambiguous feedback (4)	Pearson's r	0.02
		significance	0,985
5	Concentration on the Task at Hand (5)	Pearson's r	0,06
		significance	0,322
6	**Sense of control (6)**	Pearson's r	**0,12**
		significance	0,031
7	Loss of Self-Consciousness (7)	Pearson's r	0,07
		significance	0,201
8	Transformation of time (8)	Pearson's r	0,08
		significance	0,151
9	Autotelic experience (9)	Pearson's r	0,05
		significance	0,389

Pearson's correlation analysis was conducted to examine the relationship between the flow level rating and average gameplay time. The results indicated that there was no significant correlation between the flow rating and average playing time ($r = 0.06$, $p = 0.323$). This suggests that the perceived flow state during gameplay does not strongly influence the duration of individual games in a session.

There was a statistically significant **positive correlation** between **Mean Training Time In Session** and **Sense of Control** (r = 0.12, p = 0.031). This suggests that players who experienced a greater sense of control during gameplay tended to have longer average training times in a session.

On the other hand, there was a statistically significant **negative correlation** between **Mean Training Time In Session** and **Merging of Action and Awareness** (r = -0.12, p = 0.037). This implies that players who reported a higher degree of merging action and awareness in their flow state had shorter average training times in a session.

No significant correlations were found between Mean Training Time In Session and the other flow dimensions.

H.1.2.b Perceived flow state in a session is positively correlated with the amount of time elapsed since the previous game day. (Time Since Last Session, Flow State Scale)
H.1.2.c Perceived flow state in a session is positively correlated with the amount of total play time preceding the measurement on a given day. (Session Time, Flow State Scale)
H.1.2.d Perceived flow in a session is positively correlated with the amount of time left for the participant to complete the study, especially after the penultimate measurement. (Time to Training End, Flow State Scale)

The next step in the analysis was to verify whether there were any relationships between perceived flow state and the amount of time elapsed since the previous game session (**Time Since Last Session)**, the amount of total game time preceding the measurement on the day (**Session Time**), and the amount of time left for the participant to complete the study (**Time to Training End)**. For this purpose, Pearson's r correlation analysis was performed, the results of which are presented in Table 24.

The variable **Time Since Last Session** was created by subtracting the date and time of the pre-measurement game from the date and time of the end of the games on the last preceding game day. The variable **Session Time** was created by subtracting the start time of the day's games from the end time of the last game before measurement. The variable **Time To Training End** was created by subtracting from 60 hours, representing the full pool of training hours, the time the participant had already played by the time of measurement.

Table 24. Correlation of flow state and the Time Since Last Session, Session Time and Time To Training End.

			Time Since Last Session	Session Time	Time To Training End
Flow State Scale		Pearson's r	-0,05	**0,18**	0,08
		significance	0,364	<0,001	0,137
1	Challenge-Skill Balance (1)	Pearson's r	-0,09	**0,1**8	0,1
		significance	0,108	0,001	0,062
2	Merging of Action and Awareness (2)	Pearson's r	-0,05	0,10	-0,02
		significance	0,406	0,082	0,763
3	Clear goals (3)	Pearson's r	0,04	**0,20**	-0,01
		significance	0,443	<0,001	0,862
4	Unambiguous feedback (4)	Pearson's r	0,06	**0,20**	0,05
		significance	0,319	<0,001	0,346
5	Concentration on the Task at Hand (5)	Pearson's r	-0,09	**0,12**	0,03
		significance	0,097	0,029	0,55
6	Sense of control (6)	Pearson's r	-0,03	**0,17**	0,1
		significance	0,652	0,003	0,083
7	Loss of Self-Consciousness (7)	Pearson's r	-0,05	0,05	0,02
		significance	0,361	0,374	0,67
8	Transformation of time (8)	Pearson's r	<0,01	0,09	0,09
		significance	0,951	0,092	0,09
9	Autotelic experience (9)	Pearson's r	**-0,11**	**0,12**	**0,12**
		significance	0,042	0,025	0,027

The analysis showed statistically significant positive relationships between the amount of total play time preceding the measurement on a given day (**Session Time**) and all dimensions of the flow level assessment, except for **Merging of action and awareness (2)**, **Loss of Self-Consciousness (7)** and **Transformation of time (8)**. In addition, we found that there was a statistically significant positive relationship between **Time To Training End** and **Autotelic experience (9)**, as well as a statistically significant negative relationship between **Time Since Last Session** and **Autotelic experience (9)**. The results obtained mean that as the length of the training session (**Session Time**) increased, the level of flow increased, and that as the **Time To Training End** of the training session shortened and the **Time Since Last Session** the level of **Autotelic experience (9)** decreased. It should be noted, however, that the recorded relationships were found to be weak ($r < 0.3$).

Is there a relationship between the flow level assessment and the difficulty level?

H.1.3. Perceived flow state in a session is positively correlated with the difficulty level? (Match Map Level, Flow State Scale)

Next, it was examined whether there was a relationship between flow rating and difficulty level. For this purpose, Spearman's rho correlation analysis was performed. The results of the analyses are shown in Table 25.

Table 25. Correlation of flow level rating and level of gameplay sophistication

			Difficulty level
Flow State Scale		Spearman's *rho*	**0,32**
		significance	<0,001
1	Challenge-Skill Balance (1)	Spearman's *rho*	**0,3**9
		significance	<0,001
2	Merging of Action and Awareness (2)	Spearman's *rho*	**0,34**
		significance	<0,001
3	Clear goals (3)	Spearman's *rho*	**0,36**
		significance	<0,001
4	Unambiguous feedback (4)	Spearman's *rho*	**0,39**
		significance	<0,001
5	Concentration on the Task at Hand (5)	Spearman's *rho*	0,11
		significance	0,075
6	Sense of control (6)	Spearman's *rho*	**0,29**
		significance	<0,001
7	Loss of Self-Consciousness (7)	Spearman's *rho*	0,08
		significance	0,229
8	Transformation of time (8)	Spearman's *rho*	-0,02
		significance	0,794
9	Autotelic experience (9)	Spearman's *rho*	**0,15**
		significance	0,016

The analysis showed statistically significant positive relationships between the level of gameplay and the flow rating in all dimensions, except for **Concentration on the Task at Hand (5)**, **Loss of Self-Consciousness (7)** and **Transformation of time (8)**. This means that as the level of difficulty of the map increased, the level of flow assessment in the indicated dimensions increased. Noteworthy, however, is the fact that only the correlations between the level of gameplay and the overall score of the flow level assessment, **Challenge-Skill Balance (1)**, **Merging of action and awareness (2)**, **Clear goals (3)** and **Unambiguous feedback (4)**, were found to be moderately strong ($0.3 < rho < 0.5$). The other correlations noted were found to be weak ($r/rho < 0.3$).

Next, the correlations between **Flow State** in the two theoretical models and the difficulty level were verified.

Table 26. Correlations between Match Result and flow - according to models: a. Csikszentmihalyi and b. Stavrou and Zervas

N=241		FlowCsikProxy	FlowCsikExp	FlowStavProxy	FlowStavExp
Difficulty Level	rho Spearman	**0,454**	**0.208**	**0.390**	**0,184**
	significance	<0.001	0.001	<0.001	0.004

Spearman's rank correlation was computed to examine the relationship between **Difficulty level** vs. 2 models of **Flow** state, and it revealed a moderate positive correlation with: **FlowCsikProxy** (rho = 0.454, p < 0.001), **FlowStavProxy** (rho = 0.390, p < 0.001, and weak correlation with **FlowCsikExp** (rho = 0.184, p = 0.004), and **FlowStavExp** (rho = 0.208, p < 0.001).

The next step was to verify, Is there a relationship between the players' perceived flow state and their proficiency in the game.

H.1.4.a Perceived Flow State positively correlates with telemetry data (Action per Minute/APM, Hotkeys, PACs Per Minute) session by session (N = 261) and negatively with PACs Action Latency.

Flow State data and selected telemetry metrics from matches played before flow measurement (N = 261) were compiled: Match Won, Match Played, Average Action per minute APM, Hotkeys Total, First Attack Move Time, Total Army Units, PACs Per Minute and PACs Action Latency. The selection of indicators was based on research on the most commonly used Star Craft II indicators considered authoritative.

The same telemetric data were also used to create an index of correlation (Spearman) between telemetric data and Flow State for each subject, the index was used for subsequent analyses with cognitive variables.

Table 27. Correlations between Flow State and telemetry variables

N=241		Match Won	Match Played	AvgAPM	Hotkeys Total	First Attack Move Time	Total Army Units	PACs Per Minute	PACs Action Latency
Flow State	*rho* Spearman	0.034	-0.112	**0.158**	**0.333**	**0.336**	**0.197**	**0.331**	**-0.290**
	significance	0.581	0.071	0.010	<0.001	<0.001	0.001	<0.001	<0.001

Spearman's rank correlation was computed to assess the relationship between Flow State and variables: Match Played, Avg APM, Hotkeys Total, First Attack Move Time, TotalArmyUnits, PACs Per Minute oraz PACs ActionLatency. There was a positive correlation between **Flow** and **average number of hotkeys pressed per minute (**Hotkeys)**, First Attack Move Time, Total Army Units** oraz **PACs Per Minute** and a negative correlation between **Flow Mean** and **PACs Action Latency**. The results can be found in Table 27.

Pearson's rank correlation was computed to assess the relationship between dimensions of Flow and telemetric variables, of which only **Merging of action and awareness (2)** was significantly related. There was a 2 positive strong correlations between **Merging of action and awareness (2)** and: **average actions per minute** (Action per Minute APM), r(25) = 0.570, p = 0.002 and **perception action cycle per minute** (PACs Per Minute), r(25) = 0.559, p = 0.002. A negative correlation is also observed with **average delay from the beginning of the perception action cycle to the first action taken in that PAC** (PACs Action Latency), r(25) = -0.270, p = 0.173. The results can be found in Table 27.

H.1.4.b Perceived Flow State correlates with telemetry data in the two snapshots: last and first match before/after flow measurement. Positively correlates with **average actions per minute** (APM), **average number of hotkeys pressed per minute (**Hotkeys), **perception action cycle per minute (**PACs Per Minute) and negatively with the **average delay from the beginning of the perception action cycle to the first action taken in that PAC** (PACs Action Latency).

Spearman's rank correlation was computed to assess the relationship between telemetric data and **Flow State**, as well as between telemetric data and proximate and experimental variables of the two theoretical flow models. Telemetric data were included in the two snapshots - in the last matches before the flow measurement session (last), in the first matches that occurred after the flow measurement (first) and finally the change (change) that occurred between the two variables (first - last) was shown.

PACs Per Minute_**last** > flow measurement > PACs PerMinute_**first**

To assess the relationship between telemetric data and flow state and the proximal and experiential variables in two theoretical flow models, Spearman's rank correlation was performed. The results are presented in Table 28, and showed a positive correlation only with one telemetry variable - PACs Per Minute. Specifically, PACs Per Minute_last exhibited a strong positive correlation with Flow_State (rho = 0.638, p < 0.001). Furthermore, PACs Per Minute_last was also strongly positively correlated with FlowCsikProxy (rho = 0.609, p < 0.001), FlowCsikExp (rho = 0.528, p = 0.003), FlowStavProxy (rho = 0.678, p < 0.001) and FlowStavExp (rho = 0.504, p = 0.005). Spearman's rank correlation also revealed a relationship between PACsPerMinute_first and FlowCsikProxy (rho = 0.160, p = 0.005).

Table 28. Correlations between PACs per Minute (first and last) and flow - in traditional attitude and according to models: a. Csikszentmihalyi and b. Stavrou and Zervas

N=29		FlowCsik Proxy	FlowCsik Exp	FlowStav Proxy	FlowStav Exp	Flow State
PACs Per Minute first	rho Spearman	0,311	0,268	**0,372**	0,316	0,355
	significance	0,1	0,159	0,047	0,095	0,059
PACs Per Minute last	rho Spearman	**0,609**	**0,528**	**0,678**	**0,504**	**0,638**
	significance	<0,001	0,003	<,001	0,005	<,001

There was a positive correlation between **Flow State**, proximate and experimental variables in the two flow theoretical models only in the case of one telemetry variable **- PACs Per Minute**. The results can be found in Table 28.

Spearman's rank correlation was computed to assess the relationship between z **Flow State** and **PACs Per Minute variables** and showed one positive correlation with **PACs Per Minute variable: PACs Per Minute last (**rho = 0.638, p < 0.001). Similarly Spearman's rank correlation showed also positive relationships between number of PACs per Minute from the last matches and **FlowCsikProxy** (rho = 0.609, p < 0.001), **FlowCsikExp (**rho = 0.528, p = 0.003), **FlowStavProxy** (rho = 0.678, p < 0.001) and **FlowStavExp** (rho = 0.504, p = 0.005). Spearman's rank correlation also showed the relationship between **PACsPerMinute_first** and **FlowCsikProxy** (rho = 0.160, p = 0.005).

H.1.4.c Perceived Flow State is positively correlated with averaged telemetry scores between groups, separated based on individual differences in tendency to experience high/low flow. (APM, Hotkeys, PACs, First Army, Flow State)

In the next step, the relationships between the telemetric changes and the Flow State measurements in each measurement were checked. Telemetric data were considered in 2 snapshots - in the last matches before the flow session measurement (last), in the first matches that occurred after the flow measurement (first) and finally the change (change) that occurred between the two variables (first - last) was shown (N=27).

Spearman's rank correlation was computed to assess the relationship between FSS_First and telemetric data. There was a positive strong correlation between **PACs PerMinute_last** (rho = 0.521, p = 0.005) and positive moderate correlation between **Flow** and **Average Aaction per Minute last** (rho = 0.402, p = 0.038).

Summary

To answer the first research question, hypotheses were analyzed regarding the relationship of flow and its dimensions with telemetry variables: Mean Match Result, Mean Match Results by Measurement Point, Mean Match Result in the Last Session, Last Match Result In Last Session, Mean Training Time in Session, Time Since Last Session, Session Time, Time to Training End, Match Map Level, APM, PACs per Minute, PACs Action Latency, First Army Units, Hotkeys.

The results of the analyses indicate a **relationship between a player's level of flow and performance in real-time strategy** (RTS) games such as Star Craft II, as indicated by various telemetry variables.

However, the correlation varies in strength and significance across different aspects of gameplay, flow dimensions, and individual players. While certain components of the flow state, like **Challenge-Skill Balance, Unambiguous Feedback**, and **Sense of Control**, showed a **positive correlation** with **game performance**, others, like Loss of Self-Consciousness and Transformation of Time, showed no significant correlation.

Furthermore, the data indicated that certain gameplay metrics, such as **Average Actions Per Minute** (average Action per Minute/ APM), **Hotkeys Total, First Attack Move Time, Total Army Units**, and **Perception-Action Cycles Per Minute** (PACs Per Minute), were **positively associated with higher flow states.** It also suggested that **faster-paced action and decision-making before achieving a flow state** could **enhance the flow experience**, thus **improving game performance**.

A relationship was also observed between the **level of gameplay sophistication** (Difficulty level) and the **flow rating in most dimensions**. The **more challenging the game**, the more likely it induced a state of flow, especially in dimensions related to **Challenge-Skill Balance, Merging Action and Awareness, Clear Goals, and Unambiguous Feedback**.

Finally, the data suggested a correlation between **gameplay time** and **session dynamics** and **the level of flow.** It showed that the **more time players spent in the game, the more likely they were to experience flow**, except for a few flow dimensions.

However, the research also found that while these **correlations exist**, they were relatively **weak**, indicating that the flow state is **only one of the many factors influencing game performance**. Other factors, like player skill, strategy, game complexity, and individual differences, may also play a crucial role in gaming performance.

So, to answer the first research question, a player's level of flow state is related to his real-time strategy (RTS) game performance, but the relationship is complex and influenced by other factors as well.

5.3.2. Are there behavioral and mental predictors that can identify a player's predisposition to achieve a higher level of flow?

For the second purpose of the study, the subjects underwent two types of measurements. At the beginning of the study, they completed tests related to: **flow** as a trait, **personality**, level of **intelligence,** and **load during the learning process, and perceived flow state**.

1. **Does the level of susceptibility to flow relate to flow when learning complex skills during the game?**

H.2.1 Flow as a trait is positively correlated with perceived flow state during the learning process. (dispositional flow/ PDFS-2, flow state/ PFSS-2)

The first step was to compare the results of the **Flow** scale with the results of the **Dispositional Flow** scale on both the general and specific dimensions. For this purpose, a Student's t test for dependent samples was performed, the results of which are presented in Table 29.

Table 29. Comparison of FSS-2 scale scores with DFS-2 scale scores

	DFS-2 (n = 47)		FSS-2 (n = 47)				
	M	*SD*	*M*	*SD*	*t*	*p*	Cohen's d
Total scale score	122,91	17,51	123,00	19,98	-0,04	0,971	0,01
Challenge-Skill Balance (1)	**13,79**	**2,77**	**12,47**	**2,98**	**3,54**	**<0,001**	**0,52**
Merging of Action and Awareness (2)	12,77	2,25	12,04	3,18	1,92	0,061	0,28
Clear goals (3)	14,17	2,94	13,68	3,15	0,96	0,342	0,14
Unambiguous feedback (4)	14,40	2,82	14,11	2,66	0,79	0,433	0,12
Concentration on the Task at Hand (5)	14,17	2,45	15,43	2,50	-2,89	0,005	0,42
Sense of control (6)	13,55	2,51	13,36	3,19	0,43	0,670	0,06
Loss of Self-Consciousness (7)	**12,40**	**4,53**	**15,51**	**3,34**	**-5,37**	**<0,001**	**0,78**
Transformation of time (8)	13,60	3,19	13,66	3,99	-0,16	0,871	0,02
Autotelic experience (9)	**14,06**	**2,94**	**12,74**	**4,08**	**2,30**	**0,026**	**0,34**

The analysis showed statistically significant differences on measures of **Challenge-Skill Balance (1), Concentration on the Task at Hand (5), Loss of Self-Consciousness (7)** and **Autotelic experience (9)**. It turned out that when measured with the Flow scale, the subjects had higher scores on **Concentration on the Task at Hand (5)** and **Loss of Self-Consciousness (7)**, as well as lower scores on **Challenge-Skill Balance (1)** and **Autotelic experience (9).** For the other variables analyzed, there were no statistically significant differences between measurements taken with the **Flow** and **Dispositional Flow** scales. Then Pearson correlation analysis between the Dispositional Flow Scale-2 (DFS-2) and the Flow State Scale - 2 (FSS-2) was performed.

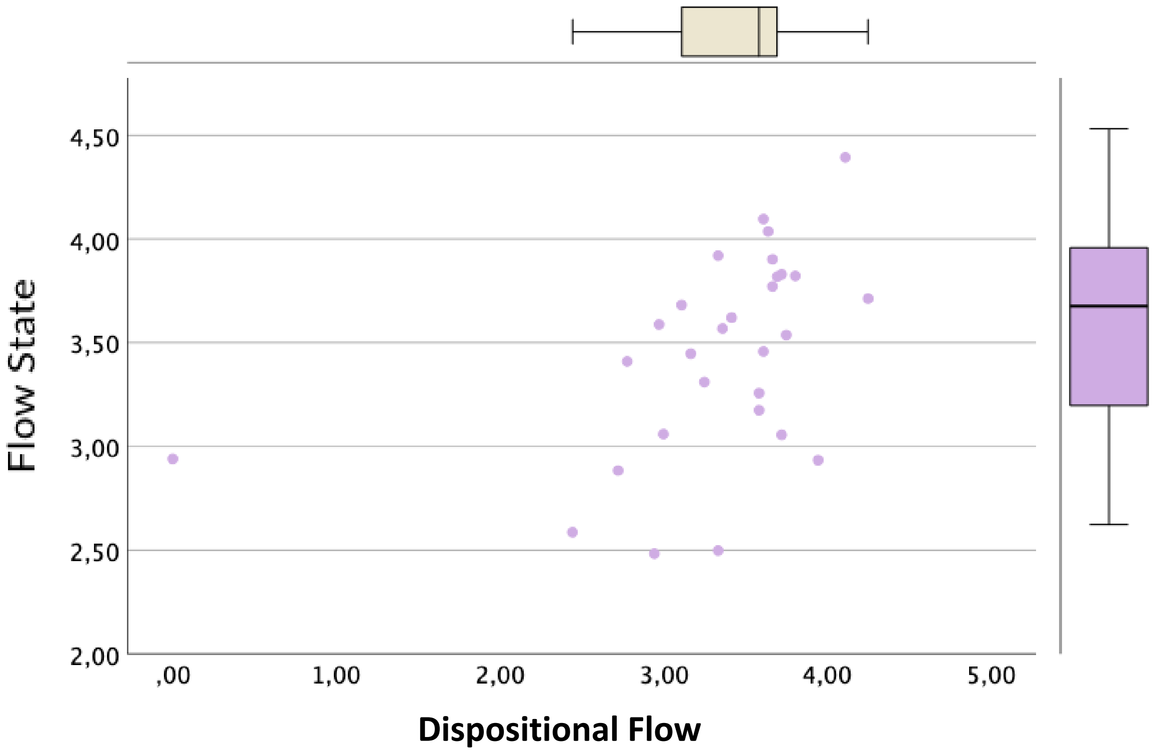


Figure 13. Relationship between Dispositional Flow (PDFS) and Flow State (PFSS)

A **strong positive correlation** (r = 0.633, p < 0.01) was found between the **Dispositional Flow Scale - 2 (DFS-2)** and the **Flow State Scale - 2 (FSS-2)**. This indicates that those more prone to experience flow (higher DFS-2 scores) are also more likely to encounter a flow state (higher FSS - 2 scores). This correlation was statistically significant.

After checking the middle dimensions of the flow, the relationships between the dimensions of the disposition flow and the flow as a feature were verified (Table 30).

Table 30. Correlation results between Dispositional Flow State and Flow State

Flow State		**Dispositional Flow**								
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Challenge-Skill Balance (1)	Pearson's r	**.608**	**.452**	**.464**	**.334**	**.299**	**.521**	0.059	**.429**	**.374**
	significance	<.001	0.001	0.001	0.022	0.041	<.001	0.693	0.003	0.01
Merging of Action and Awareness (2)	Pearson's r	**.406**	**.592**	**.404**	**.367**	0.223	**.460**	0.045	**.420**	**.332**
	significance	0.005	<.001	0.005	0.011	0.132	0.001	0.763	0.003	0.023

Clear Goals (3)	Pearson's r	0.231	0.288	**.341**	**.297**	0.209	**.296**	0.23	0.24	**.308**
	significance	0.119	0.05	0.019	0.043	0.16	0.043	0.121	0.104	0.035
Unambiguous Feedback (4)	Pearson's r	**.378**	0.243	**.441**	**.556**	**.367**	**.365**	0.132	0.177	0.272
	significance	0.009	0.099	0.002	<.001	0.011	0.012	0.376	0.234	0.065
Concentration on the Task at Hand (5)	Pearson's r	**.452**	**.345**	0.232	-0.016	0.279	0.164	-0.019	**.351**	**.337**
	significance	0.001	0.017	0.116	0.914	0.058	0.27	0.9	0.016	0.021
Sense of Control (6)	Pearson's r	**.432**	**.376**	**.477**	**.401**	0.242	**.441**	0.049	**.295**	0.262
	significance	0.002	0.009	<.001	0.005	0.101	0.002	0.746	0.044	0.075
Loss of Self-Consciousness (7)	Pearson's r	0.122	0.242	0.197	0.218	-0.056	0.174	**.528**	-0.104	-0.048
	significance	0.413	0.101	0.185	0.141	0.71	0.241	<.001	0.486	0.747
Transformation of Time (8)	Pearson's r	**.425**	**.393**	0.234	0.087	0.126	**.339**	-0.009	**.739**	**.403**
	significance	0.003	0.006	0.114	0.56	0.4	0.02	0.953	<.001	0.005
Autotelic Experience (9)	Pearson's r	**.475**	**.359**	**.291**	0.08	0.15	**.415**	0.154	**.494**	**.409**
	significance	<.001	0.013	0.047	0.594	0.314	0.004	0.302	<.001	0.004

Challenge-Skill Balance - with a strong correlation of .608 and a significance level of less than .001, this dispositional flow trait is highly correlated with its flow state counterpart. This suggests that individuals who usually balance challenges and skills well are more likely to experience this balance when learning complex skills during the game.

Merging of Action and Awareness is also highly correlated with its counterpart ($r = .592$, $p < .001$). This indicates that individuals who typically experience a merging of their actions and awareness during flow are likely to experience this merging when learning complex skills during the game.

There is a positive but less strong correlation between this dispositional trait **Clear Goals** and its counterpart in the flow state ($r = .341$, $p = .019$). This suggests that those with a propensity to set clear goals during flow experiences are more likely to do so during the learning process, although the relationship is not as strong as for the first two traits.

Trait **Unambiguous Feedback** has a significant correlation with its flow state counterpart ($r = .556$, $p < .001$). Thus, individuals who are accustomed to receiving clear feedback during flow states are more likely to perceive such feedback when learning complex skills during the game.

Dispositional flow trait **Concentration on the Task at Hand** shows a moderate correlation with its flow state counterpart (r = .452, p = .001). This suggests that individuals who generally concentrate well on the task at hand during flow experiences are likely to concentrate during the learning process as well.

The correlation between trait **Sense of Control** and its flow state counterpart is significant (r = .441, p = .002). This suggests that individuals who typically feel a sense of control during flow experiences are likely to feel the same during the learning process.

There is a weak, non-significant correlation between trait **Loss of Self-Consciousness** and its flow state counterpart (r = .174, p = .241). This suggests that while individuals might typically lose self-consciousness during flow experiences, they might not necessarily experience this during the learning process.

This dispositional flow trait **Transformation of Time** shows a strong correlation with its flow state counterpart (r = .739, p < .001). This implies that individuals who typically experience a transformation of time during flow experiences are likely to experience it when learning complex skills during the game.

The trait **Autotelic Experience** also shows a strong correlation with its flow state counterpart (r = .494, p < .001). This suggests that individuals who usually find flow experiences intrinsically rewarding (autotelic) are likely to find the learning process rewarding as well.

In a detailed look at dispositional flow traits and flow states during complex skill acquisition in games, **significant positive correlations** were seen for: **Challenge-Skill Balance, Merging of Action and Awareness, Clear Goals, Unambiguous Feedback, Concentration on the Task at Hand, Sense of Control, Transformation of Time, and Autotelic Experience** (r ranges from .341 to .739, p < .05). However, Loss of Self-Consciousness differed, showing a non-significant correlation (r = .174, p = .241), possibly due to cognitive load or the need for self-reflection during complex skill learning.

Summing up, the study found a **significant positive correlation** (r = 0.633, p < 0.01) between the **Dispositional Flow Scale-2 (DFS-2) and the Flow State Scale (FSS),** indicating that individuals predisposed to flow are more likely to experience a flow state, particularly during complex skill learning in games. Most dispositional flow traits demonstrated significant positive correlations with their flow state counterparts, reinforcing the importance of these traits in achieving a flow state. However, Loss of Self-Consciousness deviated, showing a non-significant correlation, suggesting it may be less critical during the process due to cognitive load or the need for self-reflection.

2. Is there a relationship between flow and player's personality traits?

H.2.2.a Flow is correlated with **personality traits** (NEO FFI, PFSS-2)

The next step was to analyze a multivariable regression analysis examining the relationship between personality traits and the experience of flow. Flow, as measured by the Flow State Scale -2 (FSS - 2) and its 9 dimensions. The study focuses on five personality traits: Neuroticism, Extraversion, Openness, Agreeableness, and Consciousness. The analysis utilizes a multivariable regression approach to examine the unique contributions of each personality trait in predicting flow experiences.

Table 31. Flow vs. Big Five. Summary results of multivariate regression analyses

Dependent variable	Model factor	β	p
Mean Flow $F(5, 20) = 2.633$, $p = .05$, $R^2 = .397$	**Intercept**		**= 0.003**
	Neuroticism	**-,629**	**= 0.006**
	Extraversion	-,025	= 0.903
	Openness	,059	= 0.750
	Agreeableness	,092	= 0.653
	Consciousness	-,268	= 0.183
Challenge-Skill Balance (1) $F(5, 20) = 2.506$, $p = .021$, $R^2 = .463$	**Intercept**		**< 0.001**
	Neuroticism	**-,783**	**< 0.001**
	Extraversion	-,280	= 0.159
	Openness	,016	= 0.927
	Agreeableness	-,113	= 0.560
	Consciousness	-,179	= 0.340
Merging of Action and Awareness (2) $F(5, 20) = 0.086$, $p = .522$, $R^2 = .178$	**Intercept**		**= 0.022**
	Neuroticism	-,440	= 0.080
	Extraversion	-,240	= 0.325
	Openness	,003	= 0.987
	Agreeableness	,094	= 0.694
	Consciousness	-,207	= 0.372
Clear Goals (3) $F(5, 20) = 2.294$, $p = .084$, $R^2 = .365$	**Intercept**		**< 0.001**
	Neuroticism	**-,648**	**= 0.006**
	Extraversion	-,041	= 0.847
	Openness	-,084	= 0.660
	Agreeableness	-,007	= 0.972

	Consciousness	-,303	= 0.144
Unambiguous Feedback (4) *F*(5, 20) = 4.719, *p* = .005, R^2 = .541	**Intercept**		**< 0.001**
	Neuroticism	**-,672**	**= 0.001**
	Extraversion	,184	= 0.311
	Openness	**-,402**	**= 0.021**
	Agreeableness	-,223	= 0.220
	Consciousness	-,141	= 0.415
Focus on the Task at Hand (5) *F*(5, 20) = 3.118, *p* = .031, R^2 = .438	**Intercept**		**= 0.017**
	Neuroticism	-,376	= 0.071
	Extraversion	,161	= 0.421
	Openness	-,022	= 0.904
	Agreeableness	,335	= 0.102
	Consciousness	-,152	= 0.427
Sense of Control (6) *F*(5, 20) = 3.629, *p* = .017, R^2 = .478	**Intercept**		**< 0.001**
	Neuroticism	**-,781**	**< 0.001**
	Extraversion	-,069	= 0.719
	Openness	-,030	= 0.861
	Agreeableness	-,115	= 0.548
	Consciousness	-,367	= 0.056
Loss of Self-Consciousness (7) *F*(5, 20) = 2.167, *p* = .098, R^2 = .351	Intercept		= 0.188
	Neuroticism	-,352	= 0.113
	Extraversion	,102	= 0.633
	Openness	,023	= 0.905
	Agreeableness	,309	= 0.156
	Consciousness	-,167	= 0.416
Transformation of Time (8) *F*(5, 20) = 2.878, *p* = .041, R^2 = .418	Intercept		= 0.310
	Neuroticism	0.071	= 0.727
	Extraversion	0.066	= 0.743
	Openness	**0.445**	**= 0.023**
	Agreeableness	0.374	= 0.074
	Consciousness	-0.222	= 0.258
Autotelic Experience (9) *F*(5, 20) = 0.587, *p* = .710, R^2 = .128	Intercept		= 0.176
	Neuroticism	-,304	= 0.231
	Extraversion	-,032	= 0.898
	Openness	,216	= 0.338
	Agreeableness	-,079	= 0.750
	Consciousness	-,026	= 0.911

The multiple regression analysis revealed that the model consisting of Neuroticism, Extraversion, Openness, Agreeableness, and Consciousness significantly predicted Mean Flow, F(5, 20) = 2.633, p = .05, R2 = .397. Specifically, Neuroticism had a significant negative relationship with Mean Flow (β = -0.629, p = 0.006), suggesting that higher levels of Neuroticism were associated with lower levels of Mean Flow. However, Extraversion (β = -0.025, p = 0.903), Openness (β = 0.059, p = 0.750), Agreeableness (β = 0.092, p = 0.653), and Consciousness (β = -0.268, p = 0.183) did not significantly contribute to the prediction of Mean Flow.

Mean Flow

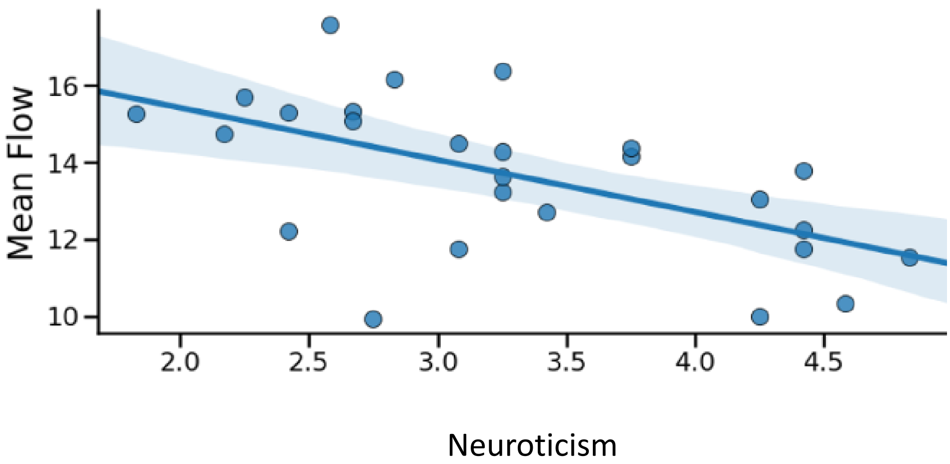


Figure 14. Relationship between Mean Flow and Neuroticism

Challenge-Skill Balance (1)

The **model was statistically significant**, F(5, 20) = 2.506, p = .021, R2 = .463. **Neuroticism** had a **significant negative association** with **Challenge-Skill Balance (1)**, β = -2.922, p < 0.001. Extraversion, Openness, Agreeableness, and Consciousness were not significant predictors, with p-values of 0.159, 0.927, 0.560, and 0.340, respectively.

The relationship between NEUr and **Challenge-Skill Balance (1)** was found to be statistically significant (R = 0.5958, p = 0.0013). **Neuroticism** had a negative direct effect on **Challenge-Skill Balance (1)** (b = -0.5371, SE = 0.1478, p = 0.0013, 95% CI [-0.8421, -0.2320]). This indicates that higher levels of **Neuroticism** were associated with lower levels of **Challenge-Skill Balance (1)**.

Unambiguous Feedback (4)

The multiple regression analysis revealed significant findings for the influence of personality traits on **Unambiguous Feedback**. The overall model was significant, F(5, 20) = 4.719, p = .005, and it accounted for 54.1% (R2 = .541) of the variance in Unambiguous Feedback.

The results indicated that **Neuroticism** had a **significant negative effect** on Unambiguous Feedback (β = -2.165, p = 0.001), suggesting that individuals with higher levels of Neuroticism tended to perceive unambiguous feedback less positively.

Extraversion, on the other hand, showed a positive but nonsignificant relationship with Unambiguous Feedback (β = 0.678, p = 0.311), indicating that individuals who were more extraverted tended to have a slightly more positive perception of unambiguous feedback, although this relationship did not reach statistical significance.

Openness had a **significant negative effect** on Unambiguous Feedback (β = -2.177, p = 0.021), indicating that individuals with higher levels of Openness tended to perceive unambiguous feedback less positively.

Agreeableness and Conscientiousness did not show significant effects on Unambiguous Feedback. The beta coefficients for Agreeableness (β = -1.600, p = 0.220) and Conscientiousness (β = -0.515, p = 0.415) indicated nonsignificant relationships with Unambiguous Feedback.

In summary, this study revealed that **Neuroticism** and **Openness** significantly influenced the perception of unambiguous feedback. Individuals with higher levels of Neuroticism and Openness tended to perceive unambiguous feedback less positively. Extraversion, Agreeableness, and Conscientiousness did not show significant effects on the perception of **Unambiguous Feedback**.

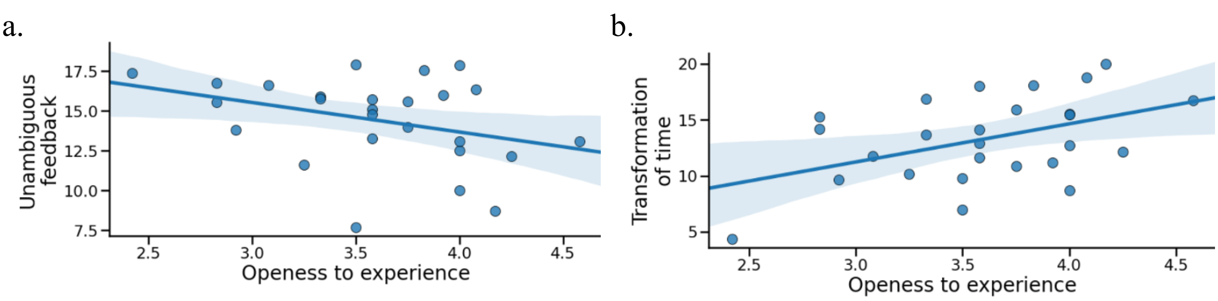


Figure 15. Relationship between a. Unambiguous Feedback and Openness to Experience, b. Transformation of Time and Openness to Experience

Focus on the Task at Hand (5)

The regression analysis results provide insight into the influence of personality traits on the ability to **Focus on the Task at Hand**. The overall **model was statistically significant**, F(5, 20) = 3.118, p = .031, accounting for 43.8% (R2 = .438) of the variance.

In this model, none of the personality traits were found to have significant effects. Neuroticism had a negative but non-significant relationship (β = -0.376, p = 0.071), indicating that individuals higher in Neuroticism might experience some difficulty focusing, but this trend was not statistically significant.

Extraversion showed a positive but non-significant association (β = 0.161, p = 0.421). Thus, extraverted individuals might find it somewhat easier to focus on tasks, but this finding was also not statistically significant.

Openness had a slight negative non-significant relationship (β = -0.022, p = 0.904), indicating that those with higher Openness do not necessarily focus better on the task at hand. The relationship between Agreeableness and focus was also positive but not statistically significant (β = 0.335, p = 0.102).

Lastly, Conscientiousness showed a small, negative, non-significant relationship with the ability to focus on the task (β = -0.152, p = 0.427), suggesting conscientiousness doesn't significantly impact the ability to focus on the task in this context.

The results of this analysis suggest that the ability to focus on a task at hand in a state of flow isn't significantly associated with any of the Big Five personality traits. However, some trends can be noted.

Sense of Control (6)

The regression model was **statistically significant**, F(5, 20) = 3.629, p = .017, accounting for 47.8% (R2 = .478) of the variance in Sense of Control.

Neuroticism was found to have a **significant negative effect** on **Sense of Control** (β = -0.781, p < 0.001). This finding can be attributed to their tendency towards anxiety and self-doubt, which may reduce their perceived control over situations.

Extraversion, although negative, did not have a significant impact on the Sense of Control (β = -0.069, p = 0.719), indicating extraversion doesn't significantly affect the sense of control in this context.

Openness showed a small negative but non-significant effect (β = -0.030, p = 0.861), suggesting that more open individuals don't necessarily have a stronger sense of control.

Agreeableness also did not have a significant influence on the Sense of Control (β = -0.115, p = 0.548), indicating that agreeableness doesn't significantly impact the sense of control in this context.

Finally, Conscientiousness had a negative but non-significant effect (β = -0.367, p = 0.056), implying that higher conscientiousness does not significantly enhance the sense of control.

In conclusion, the analysis found that only Neuroticism significantly influenced the sense of control in a flow state, with higher levels leading to less perceived control. Other traits, including extraversion, openness, and conscientiousness, although not significant, showed a trend towards a potentially negative impact on control during flow, potentially due to their contrast with the spontaneous nature of flow states.

Transformation of Time (8)

The multiple regression analysis revealed significant findings regarding the influence of personality traits on the **Transformation of Time**. The overall **model was statistically significant**, F(5, 20) = 2.878, p = .041, and it accounted for 41.8% (R2 = .418) of the variance in the Transformation of Time.

The results indicated that **Openness** had a **significant positive effect** on the Transformation of Time (β = 3.344, p = 0.023), suggesting that individuals with higher levels of Openness tend to experience a greater transformation of time.

Agreeableness also showed a positive effect on the Transformation of Time, although it did not reach statistical significance (β = 3.725, p = 0.074). This implies that individuals with higher levels of Agreeableness may have a tendency to experience a more pronounced transformation of time, although further research is needed to establish a conclusive relationship.

Neuroticism, Extraversion, and Conscientiousness did not demonstrate significant effects on the Transformation of Time. The beta coefficients for Neuroticism (β = 0.318, p = 0.727), Extraversion (β = 0.338, p = 0.743), and Conscientiousness (β = -1.127, p = 0.258) indicated nonsignificant relationships with the Transformation of Time.

In summary, this study suggests that **Openness plays a significant role in the Transformation of Time, with individuals higher in Openness experiencing a more pronounced transformation**. Agreeableness also showed a positive relationship with the

Transformation of Time, although it did not reach statistical significance. Neuroticism, Extraversion, and Conscientiousness did not demonstrate significant effects on the perception and experience of time.

Autotelic Experience (9)

The model was not significant, F(5, 20) = 0.587, p = .710, R2 = .128. None of the model factors (Neuroticism, Extraversion, Openness, Agreeableness, and Consciousness) showed significant associations with **Autotelic Experience (9)**.

In conclusion, the multivariable regression analysis revealed that **higher levels of Mean Flow** and some of its dimensions (**Challenge-Skill Balance (1)**, **Clear Goals (3)**, **Unambiguous Feedback (4)**, and **Sense of Control (6)**) was consistently **associated with lower Neuroticism**, indicating a **negative impact of Neuroticism** on the experience of flow. **Openness** showed a **positive association** with **Transformation of Time (8)**. However, Extraversion, Agreeableness, and Consciousness did not significantly predict flow experiences across the dimensions examined. These findings suggest that certain personality traits, particularly Neuroticism and Openness, may influence the experience of flow.

H.2.2.b Do neuroticism and agreeableness affect a player's performance (PACs per Minute) in a game?

Neuroticism

In a series of mediation analyses, the PROCESS procedure in SPSS Version 4.2 (Hayes, 2022) was used to investigate the indirect effects of **Neuroticism (P)** on the telemetric variable **PACs per Minute (DV)** through various mediator variables.

Mediator - Mean Flow

The objective of the first analysis was to determine the impact of **Neuroticism (P) on PACs per Minute (DV), with Mean Flow acting as a mediator (M).** In the first model, where Mean Flow was the outcome variable, the R-squared value was .3249. This indicates that roughly 32.49% of the variability in Mean Flow was accounted for by the predictor Neuroticism. The model was statistically significant, F(1, 24) = 11.55, p = .0024. It was found that Neuroticism significantly predicted Mean Flow, b = - .3390, t(24) = -3.3987, p = .0024, with a 95% confidence interval ranging from - .5448 to - .1331.

For the second model, with PACs per Minute as the outcome variable, the R-squared value was .1716, suggesting that about 17.16% of the variability in PACs per Minute was accounted for by the predictors Neuroticism and Mean Flow. The model was not statistically significant, F(2, 23) = 2.38, p = .1148. The results showed that Neuroticism did not significantly predict PACs per Minute, b = - .0569, t(23) = -1.8748, p = .0736, with a 95% confidence interval ranging from - .1197 to .0059. Mean Flow was also not found to be a significant predictor of PACs per Minute, b = - .1014, t(23) = -1.9866, p = .0590, with a 95% confidence interval ranging from - .2071 to .0042.

In terms of direct and indirect effects of Neuroticism on PACs per Minute, the direct effect of Neuroticism on PACs per Minute was not significant, with a p-value of .0736. The **indirect effect of Neuroticism on PACs per Minute through Mean Flow was significant,** with a bootstrap confidence interval that did not include zero (.0020 to .0800). This demonstrates that **Mean Flow plays a significant mediating role between Neuroticism and PACs per Minute.**

Mediator - Challenge-Skill Balance (1)

The next MATRIX procedure was performed using the PROCESS Procedure for SPSS Version 4.2, as developed by Hayes (2022). This analysis aimed to explore the impact of **Neuroticism (P) on PACs per Minute (DV), with Challenge-Skill Balance (M) serving as the mediator.** A sample size of 26 participants was included in this procedure.

In the **first model**, where Challenge-Skill Balance was the outcome variable, the R-squared value was .3549. This signifies that about 35.49% of the variability in Challenge-Skill Balance was accounted for by the predictor Neuroticism. The model was **statistically significant**, F(1, 24) = 13.20, p = .0013. The results indicated that **Neuroticism significantly predicted Challenge-Skill Balance**, b = - .5371, t(24) = -3.6339, p = .0013, with a 95% confidence interval ranging from - .8421 to - .2320.

In the **second model,** with PACs per Minute as the outcome variable, the R-squared value was .3589, suggesting that about 35.89% of the variability in PACs per Minute was accounted for by the predictors Neuroticism and Challenge-Skill Balance. The model was statistically significant, F(2, 23) = 6.44, p = .0060. It was found that **Neuroticism significantly predicted PACs per Minute**, b = - .0785, t(23) = -2.8731, p = .0086, with a 95% confidence interval ranging from - .1350 to - .0220. Additionally, **Challenge-Skill**

Balance was a significant predictor of PACs per Minute, b = - .1042, t(23) = -3.4379, p = .0022, with a 95% confidence interval ranging from - .1669 to - .0415.

In terms of direct and indirect effects of Neuroticism on PACs per Minute, the **direct effect of Neuroticism on PACs per Minute was significant**, with a p-value of .0086. The **indirect effect of Neuroticism on PACs per Minute through Challenge-Skill Balance was also significant**, with a bootstrap confidence interval that did not include zero (.0228 to .1038), indicating that **Challenge-Skill Balance plays a significant mediating role between Neuroticism and PACs per Minute.**

Mediator - Clear Goals (3)

The following analysis verified the impact of **Neuroticism (P) on PACs per Minute (DV), with Clear Goals serving as a mediator (M)**. A sample size of 26 participants was utilized for the procedure.

For the **first model**, with Clear Goals as the outcome variable, the R-squared value was .2684, indicating that approximately 26.84% of the variability in Clear Goals was accounted for by the predictor Neuroticism. The model was statistically significant, F(1, 24) = 8.80, p = .0067. It was found that **Neuroticism significantly predicted Clear Goals**, b = - .3725, t(24) = -2.9672, p = .0067, with a 95% confidence interval ranging from - .6316 to - .1134.

In the **second model**, where PACs per Minute was the outcome variable, the R-squared value was .1817, implying that about 18.17% of the variability in PACs per Minute could be accounted for by the predictors Neuroticism and Clear Goals. The model was marginally significant, F(2, 23) = 2.55, p = .0997. The results showed that Neuroticism did not significantly predict PACs per Minute, b = - .0536, t(23) = -1.8494, p = .0773, with a 95% confidence interval ranging from - .1136 to .0064. **Clear Goals was also found to be a significant predictor of PACs per Minute**, b = - .0834, t(23) = -2.0689, p = .0500, with a 95% confidence interval ranging from - .1668 to .0000.

In terms of direct and indirect effects of Neuroticism on PACs per Minute, the direct effect of Neuroticism on PACs per Minute was not significant, with a p-value of .0773. The **indirect effect of Neuroticism on PACs per Minute through Clear Goals was significant**, with a bootstrap confidence interval that did not include zero (.0022 to .0826). This indicates that **Clear Goals plays a significant mediating role between Neuroticism and PACs per Minute.**

Mediator - Unambiguous Feedback (4)

An analogous process was carried out to investigate the impact of **Neuroticism (P) on PACs per Minute (DV), with Unambiguous Feedback (M) acting as a mediating variable.** The sample consisted of 26 participants.

The **initial model**, with Unambiguous Feedback as the outcome variable, yielded an R-squared value of .3007, suggesting that Neuroticism accounted for about 30.07% of the variance in Unambiguous Feedback. The model was statistically significant, F(1, 24) = 10.32, p = .0037. Furthermore, **Neuroticism significantly predicted Unambiguous Feedback**, b = - .4417, t(24) = -3.2128, p = .0037, with a 95% confidence interval ranging from - .7255 to - .1580.

The **secondary model**, with PACs per Minute as the outcome variable, resulted in an R-squared value of .2816, indicating that the predictors (Neuroticism and Unambiguous Feedback) could account for about 28.16% of the variance in PACs per Minute. This model was statistically significant, F(2, 23) = 4.51, p = .0223. **Neuroticism significantly predicted PACs per Minute**, b = - .0658, t(23) = -2.3697, p = .0266, with a 95% confidence interval from - .1233 to - .0084. Additionally, **Unambiguous Feedback significantly predicted PACs per Minute**, b = - .0980, t(23) = -2.8416, p = .0092, with a 95% confidence interval from - .1693 to - .0267.

In terms of direct and indirect effects of Neuroticism on PACs per Minute, the **direct effect was found to be significant**, p = .0266. The **indirect effect of Neuroticism on PACs per Minute via Unambiguous Feedback was also significant**, as the bootstrap confidence interval excluded zero (.0099 to .0910), suggesting that Unambiguous Feedback does mediate the relationship between Neuroticism and PACs per Minute.

Mediator - Sense of Control (6)

The last dimension that proved to have moderating potential was Sense of Control (6). The aim of this study was to explore the impact of **Neuroticism (P) on PACs per Minute (DV), with Sense of Control (M) serving as a mediator.** A total of 26 participants were included in the sample.

In the **initial model** with Sense of Control as the outcome variable, the R-squared value was .3471, suggesting that Neuroticism accounts for approximately 34.71% of the variance in Sense of Control. This model was statistically significant, F(1, 24) = 12.76, p = .0015. **Neuroticism was found to significantly predict Sense of Control**, b = - .4658, t(24) = -3.57, p = .0015, with a 95% confidence interval ranging from - .7349 to - .1967.

The **subsequent model**, with PACs per Minute as the outcome variable, resulted in an R-squared value of .3665. This implies that the predictors (Neuroticism and Sense of Control) explain around 36.65% of the variance in PACs per Minute. The model was statistically significant, $F(2, 23) = 6.65$, $p = .0053$. **Neuroticism significantly predicted PACs per Minute**, b = - .0782, t(23) = -2.89, p = .0081, with a 95% confidence interval from - .1340 to - .0223. **Sense of Control was also a significant predictor of PACs per Minute,** b = - .1195, t(23) = -3.49, p = .0019, with a 95% confidence interval from - .1901 to - .0488.

Regarding the direct and indirect effects of Neuroticism on PACs per Minute, the **direct effect was significant**, p = .0081. The **indirect effect of Neuroticism on PACs per Minute via Sense of Control was also significant**, as the bootstrap confidence interval did not contain zero (.0211 to .1172), suggesting a mediation effect of Sense of Control.

The other dimensions of the flow did not show moderating potential in the study area. All findings were derived with a 95% confidence level, and 5000 bootstrap samples were used for the percentile bootstrap confidence intervals.

In subsequent steps, other personality traits were similarly examined. The only one that showed significant effects was Agreeableness.

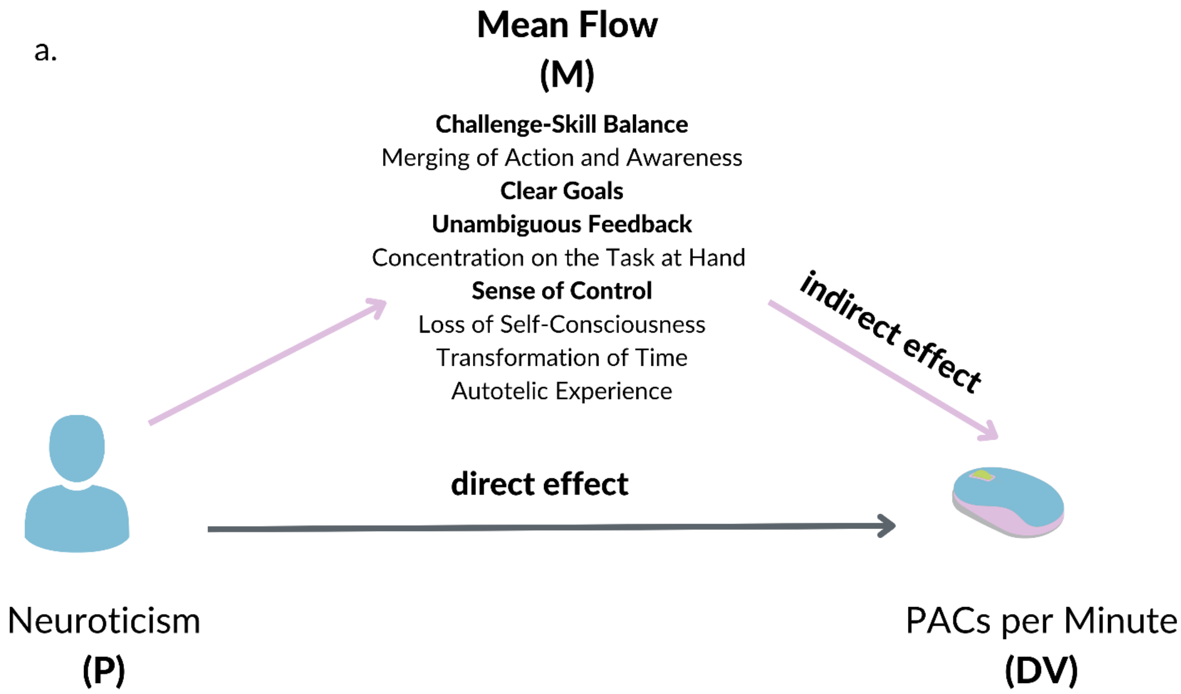
Agreeableness

In a series of mediation analyses, the PROCESS procedure in SPSS Version 4.2 (Hayes, 2022) was used to investigate the indirect effects of **Agreeableness (P)** on the telemetric variable **PACs per Minute (DV)** through various mediator variables. The sample consisted of 26 participants.

Mediator - Mean Flow

The analysis aimed to examine the effect of **Agreeableness (P) on PACs per Minute (DV) with Mean Flow (M) as a mediator** in a sample of 26 participants.

For the model with Mean Flow as the outcome variable, the R-squared value was .0974, indicating that approximately 9.74% of the variance in Mean Flow can be explained by Agreeableness. However, the model was not statistically significant, $F(1, 24) = 2.5886$, $p = .1207$. Agreeableness did not significantly predict Mean Flow, with a coefficient of .4129, t(24) = 1.6089, p = .1207.



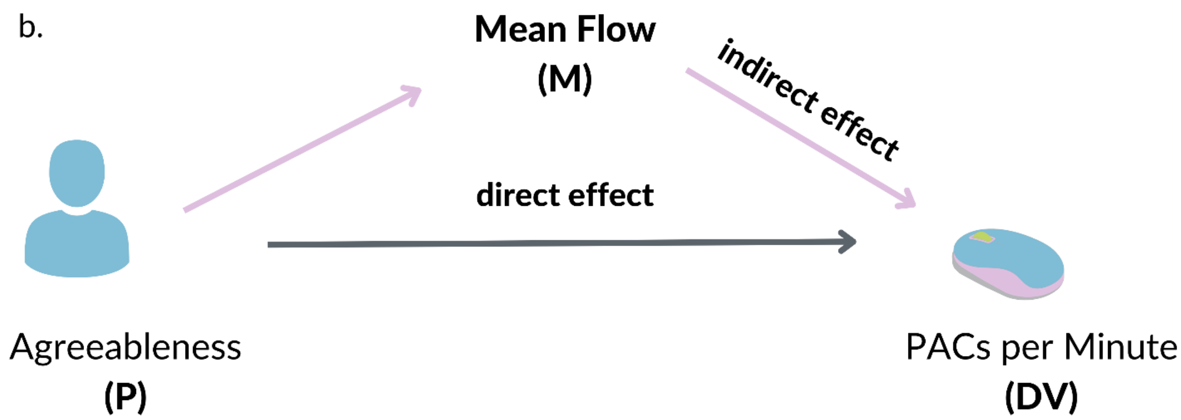


Figure 16. a. Flow dimensions, which are mediators between Neuroticism and PACs per Minute, b. Only the Mean Flow score was a mediator between Agreeableness and PACs per Minute.

In the model with PACs per Minute as the outcome variable, the predictors (Agreeableness and Mean Flow) accounted for 38.42% of the variance in PACs per Minute, as indicated by the R-squared value of .3842. The model was statistically significant, $F(2, 23) = 7.1764$, $p = .0038$. Agreeableness significantly predicted PACs per Minute, with a coefficient of .1793, t(23) = 3.5600, p = .0017. However, Mean Flow had a significant negative effect on PACs per Minute, with a coefficient of - .0892, t(23) = -2.3420, p = .0282. The **direct effect** of Agreeableness on PACs per Minute was **statistically significant** (p = .0017). The **indirect effect** of Agreeableness on PACs per Minute through Mean Flow was also **statistically significant**, with a bootstrap confidence interval that does not include zero (- .0907 to - .0001).The results were reported at a 95% confidence level, and 5000 bootstrap samples were used to estimate the percentile bootstrap confidence intervals.

In conclusion, the study analyzed the effects of neuroticism and agreeableness on a player's performance, specifically PACs per Minute, mediated by various flow dimensions. Five of the flow dimensions showed significant mediation between Neuroticism and PACs per Minute:

- Neuroticism significantly predicted Mean Flow, and although it didn't directly predict PACs per Minute, the indirect effect through Mean Flow was significant. Thus, Mean Flow significantly mediates the effect of Neuroticism on PACs per Minute.
- Neuroticism significantly predicted both Challenge-Skill Balance and PACs per Minute. Furthermore, the indirect effect of Neuroticism on PACs per Minute through Challenge-Skill Balance was significant, indicating this dimension as a significant mediator.
- Neuroticism significantly predicted Clear Goals, but not directly PACs per Minute. However, Clear Goals significantly mediates the impact of Neuroticism on PACs per Minute.
- Neuroticism significantly predicted Unambiguous Feedback and PACs per Minute. Also, the indirect effect of Neuroticism on PACs per Minute via Unambiguous Feedback was significant, showing it as a significant mediator.
- And finally Neuroticism significantly predicted Sense of Control and PACs per Minute. The indirect effect of Neuroticism on PACs per Minute via Sense of Control was also significant, indicating this dimension as a significant mediator.

Other dimensions of flow did not show significant mediation.

For Agreeableness, only Mean Flow showed significant mediation. Agreeableness significantly predicted PACs per Minute, but not Mean Flow. However, the indirect effect of Agreeableness on PACs per Minute through Mean Flow was significant.

In summary, **Neuroticism impacts player performance** (PACs per Minute) **via mediation by five flow dimensions,** while **Agreeableness impacts performance through**

Mean Flow. **Higher Neuroticism was associated with lower scores in flow dimensions and performance**, while **higher Agreeableness was linked to higher performance but lower Mean Flow**. This suggests that a player's personality traits, especially neuroticism and agreeableness, and their interaction with the flow state can significantly influence their performance in games.

3. Is there a relationship between flow and player's level of intelligence?

H.2.3 Flow is positively correlated with ratings of flow state during the learning process. (Raven Matrix, Flow State)

To examine whether perceived flow state is related to **intelligence**, Spearman correlation analysis was used. The scores of 29 participants (N = 29) were considered. Spearman's rank correlation was computed to assess the relationship between subjects' **intelligence level** and average perceived **Flow** state. No correlation was found (r(27) = -.007, p = .969). In the second step, participants were divided into those with lower (Rav_1, N = 17) and higher (Rav_2, N = 12) intelligence level scores, which also indicated no relationship (Rav_1 = r(15) = -.216, p = 0.405, Rav_2 = r(10) = .095, p = .769). In the last step - as suggested - intelligence test scores were looked at in relation to age, with similar results.

4. Is there a relationship between flow and a sense of task load during the learning process?

H.2.4a Flow is negatively correlated with the dynamics of sense of task load during the learning process. (NASA TLX, Flow State)

A multivariate regression was run to predict **Mean Flow** score from specific **NASA Task Load Index** factors (mental, physical, temporal, effort, frustration and performance). Built model turned out to be significant $F(6, 301) = 17.52$, $p < .001$, $R^2 = .258$. Obtained results indicated significant influence of effort (p = 0.008) and frustration (p < 0.001).

Separate models were then built for specific **9 Flow dimensions**. All of the created models turned out to be significant. Obtained results were presented in Table 32.

Table 32. Flow vs. NASA Task Load Index. Summary results of multivariate regression analyses

Dependent variable	Model factor	β	p
Mean Flow $F(6, 301) = 17.52$, $p < .001$, $R^2 = .258$	**Intercept**	**130.516**	**< 0.001**
	Mental	0.248	= 0.531
	Physical	0.012	= 0.969
	Temporal	0.219	= 0.527
	Effort	**0.965**	**= 0.008**
	Frustration	**-2.042**	**< 0.001**
	Performance	-0.372	= 0.069
Challenge-Skill Balance (1) $F(6, 301) = 17.51$, $p < .001$, $R^2 = .259$	**Intercept**	**13.699**	**< 0.001**
	Mental	**0.159**	**= 0.012**
	Physical	-0.049	= 0.300
	Temporal	0.072	= 0.198
	Effort	0.006	= 0.918
	Frustration	**-0.268**	**< 0.001**
	Performance	**-0.093**	**= 0.005**
Merging of Action and Awareness (2) $F(6, 301) = 8.44$, $p < .001$, $R^2 = .144$	**Intercept**	**13.733**	**< 0.001**
	Mental	0.082	= 0.152
	Physical	0.055	= 0.199
	Temporal	**-0.115**	**= 0.022**
	Effort	0.005	= 0.917
	Frustration	**-0.174**	**< 0.001**
	Performance	-0.008	= 0.770
Clear Goals (3) $F(6, 301) = 10.88$, $p < .001$, $R^2 = .178$	**Intercept**	**15.083**	**< 0.001**
	Mental	-0.052	= 0.362
	Physical	-0.009	= 0.826
	Temporal	0.057	= 0.248
	Effort	**0.154**	**= 0.003**
	Frustration	**-0.219**	**< 0.001**
	Performance	-0.049	= 0.096
Unambiguous Feedback (4) $F(6, 301) = 7.961$, $p < .001$, $R^2 = .137$	**Intercept**	**15.251**	**< 0.001**
	Mental	-0.101	= 0.094
	Physical	-0.032	= 0.477
	Temporal	0.086	= 0.105
	Effort	**0.138**	**= 0.013**
	Frustration	**-0.110**	**= 0.011**
	Performance	**-0.105**	**< 0.001**
Focus on the Task at Hand (5) $F(6, 301) = 1q.98$, $p < .001$, $R^2 = .193$	**Intercept**	**14.799**	**< 0.001**
	Mental	-0.001	= 0.986
	Physical	-0.027	= 0.461

	Temporal	-0.063	= 0.144
	Effort	**0.300**	**< 0.001**
	Frustration	**-0.165**	**< 0.001**
	Performance	-0.039	= 0.119
Sense of Control (6) $F(6, 301) = 19.86$, $p < .001$, $R^2 = .267$	**Intercept**	**14.976**	**< 0.001**
	Mental	0.030	= 0.596
	Physical	-0.012	= 0.768
	Temporal	0.019	= 0.701
	Effort	**0.126**	**= 0.016**
	Frustration	**-0.295**	**< 0.001**
	Performance	**-0.062**	**= 0.035**
Loss of Self-Consciousness (7) $F(6, 301) = 3.879$, $p < .001$, $R^2 = .072$	**Intercept**	**15.454**	**< 0.001**
	Mental	-0.108	= 0.154
	Physical	0.032	= 0.569
	Temporal	-0.060	= 0.365
	Effort	**0.281**	**< 0.001**
	Frustration	**-0.200**	**< 0.001**
	Performance	0.034	= 0.382
Transformation of Time (8) $F(6, 301) = 7.512$, $p < .001$, $R^2 = .13$	**Intercept**	**14.433**	**< 0.001**
	Mental	0.081	= 0.351
	Physical	0.116	= 0.071
	Temporal	0.061	= 0.424
	Effort	-0.048	= 0.546
	Frustration	**-0.303**	**< 0.001**
	Performance	0.016	= 0.708
Autotelic Experience (9) $F(6, 301) = 15.42$, $p < .001$, $R^2 = .235$	**Intercept**	**13.082**	**< 0.001**
	Mental	**0.157**	**= 0.027**
	Physical	-0.061	= 0.239
	Temporal	**0.163**	**= 0.008**
	Effort	0.002	= 0.974
	Frustration	**-0.306**	**< 0.001**
	Performance	-0.066	= 0.072

Effort and **Frustration** are significant predictors of **Mean Flow**. Higher levels of effort are associated with increased **Mean Flow**, while higher levels of frustration are associated with decreased **Mean Flow**. This highlights the importance of managing effort and minimizing frustration to enhance the experience of Flow.

A multivariate regression model predicting mean flow scores from specific NASA Task Load Index factors (including mental, physical, temporal, effort, frustration, and performance) was significant. It accounted for 25.8% of the variation in the flow scores. The effort and frustration dimensions of task load were significantly correlated with the mean flow score, supporting Hypothesis 2.4.

Specific flow dimensions showed distinct relationships with task load factors. Effort was positively correlated with mean flow, challenge-skill balance, clear goals, unambiguous feedback, focus on the task at hand, sense of control, and loss of self-consciousness. This suggests that **as the effort increases, individuals experience an enhanced sense of flow** (Figure 17 a.).

a. b.

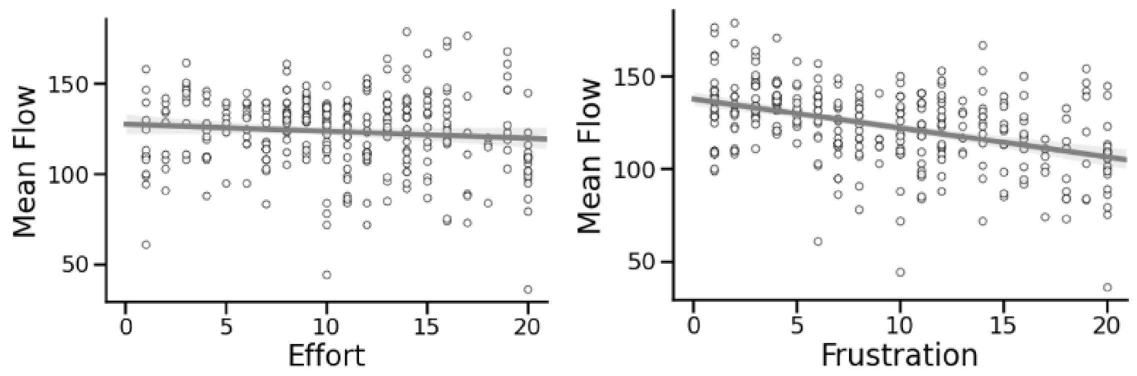


Figure 17. Results of the analysis of the relationship between: a. Mean Flow and Effort, b. Mean Flow and Frustration (NASA Task Load Index)

Frustration was negatively correlated with all dimensions of flow (Figure 17 b.). This implies that **as the level of frustration increases, the sense of flow decreases**. Mental and temporal aspects of task load were only significantly related to a few dimensions of flow. Mental load was positively correlated with challenge-skill balance and autotelic experience, while temporal load was negatively correlated with merging of action and awareness.

The performance dimension of task load showed mixed results, with **negative correlations** with **Challenge-Skill Balance, Unambiguous Feedback,** and **Sense of Control**, but no significant correlation with other flow dimensions.

In conclusion, these results provide support for the hypothesis that flow is negatively correlated with the dynamics of the sense of task load during the learning process. Specifically, an increased effort seems to enhance the flow experience, while increased frustration hinders it. However, other aspects of task load, such as mental, physical, temporal, and performance, show a more complex or negligible relationship with flow. Therefore, future research could further explore these dimensions to better understand their influence on the flow experience during the learning process.

H.2.4b There is a relationship between average flow and frustration and performance depending on the outcome of the match (win/ loss)?

In the next step, the relationship between the average flow and the sense of **task load** (NASA Task Load Index) in each dimension, depending on **Match Result**, was checked. To do this, the games were divided into 2 groups, depending on the Match Result variable: **Match Won** and **Match Lost**.

Table 33. Relationship between the average flow and the sense of task load

		Match Result	Mental	Physical	Temporal	Effort	Frustration	Performance
Mean Flow	rho Spearman	**Match Won**	0.108	0.095	0.139	0.027	**-0.332**	-**0.243**
	significance	(N=160)	0.175	0.232	0.079	0.737	<0.001	0.002
	rho Spearman	**Match Lost**	-0.091	-0.135	-.0132	-0.132	**-0.406**	**-0.327**
	significance	(N=127)	0.310	0.130	0.138	0.139	<0.001	<0.001

The Table 33 provides the results of a Spearman's rank correlation coefficient analysis conducted to understand the relationship between average flow and different dimensions of task load (mental, physical, temporal, effort, frustration, and performance) as per the NASA Task Load Index. These relationships are investigated separately for two groups divided by match results: matches won and matches lost .

For the **Match Won**, none of the task load dimensions showed a strong correlation with average flow. Frustration and performance displayed a weak negative correlation, indicating that when flow increased, frustration and performance slightly decreased. Specifically, the correlation between flow and frustration was stronger and statistically significant (rho = -0.332, $p < 0.001$), as was the correlation between flow and performance (rho = -0.243, $p = 0.002$). This suggests that players who won their matches experienced less frustration and perhaps didn't need to perform at their peak as their flow increased.

For the **Match Lost**, frustration and performance once again exhibited a statistically significant negative correlation with flow, with correlation values of rho = -0.406 and rho = -0.327, respectively. The correlation was even stronger for the frustration dimension in this group, indicating that as flow increased, frustration decreased more noticeably among players who lost their matches. Similarly, the negative correlation with performance suggests that as flow increased, performance slightly decreased for these players.

In both groups, the effort dimension showed no significant correlation with flow. The mental, physical, and temporal dimensions also showed no significant correlation with flow in either group, suggesting that these aspects of task load may not strongly influence flow regardless of match results.

In summary, the strongest and most consistent patterns identified across both groups indicate a **significant negative correlation between flow and frustration** and **between flow and performance.** However, the relationship with performance is more nuanced, as a high state of flow could indicate a state of optimal performance rather than low performance.

Summary

The study aimed to identify mental predictors of a player's potential to achieve high flow levels. Aspects such as **dispositional flow, personality traits, intelligence** level **and task load** were examined.

The study revealed a **strong positive correlation** between a player's **predisposition to flow and the experience of flow** during complex skill learning. Significant differences were noted in **Challenge-Skill Balance, Concentration on Task, Loss of Self-Consciousness,** and **Autotelic Experience**. However, the Loss of Self-Consciousness showed a weak correlation.

The study also examined the correlation between the five major personality traits and the flow state. **Neuroticism showed a negative impact on flow**. **Openness showed a positive correlation** with losing track of time while in a flow state. Extraversion, Agreeableness, and Consciousness showed minimal impact on flow.

Neuroticism significantly predicted flow and its dimensions, impacting player performance in the game. The flow dimensions mediated the relationship between Neuroticism and Perception Action Cycle (PAC) per Minute. **Agreeableness also affected player performance,** with **Mean Flow mediating the relationship between Agreeableness and PACs per Minute**.

No significant correlation was found **between perceived flow state and intelligence** level ($r(27) = -.007$, $p = .969$). **Task load significantly influenced flow, with higher effort enhancing flow and higher frustration inhibiting it.** The study's findings suggest that **managing effort and reducing frustration could enhance flow during gameplay**.

5.3.3. Will the level of flow a player achieves during training with an RTS game be related to the change in cognitive tasks after training?

To answer research question 3, the behavioral outcomes fromt: **Memory Updating, Task Switching, VMDD** and **Stop Signal** were used in series of analises of variance.

To test whether and to what extent there was a change between the first (T0) and fourth (T3) measurements in the context of each of the 4 cognitive tasks, ANOVA analyses were conducted, considering measurement (4: T0, T1, T2, T3) as a within-subject factor and flow level (2: high or low) as a between-subject factor.

Memory Updating

H.3.1.a Accuracy in memory updating task during the learning process of a complex skill varies according to the average flow level the participant reported when measured during the game. (Memory Updating, PFSS-2)

To test whether the accuracy in memory updating task during the learning process of a complex skill varies according to the average flow level the participant reported when measured during the game ANOVA analyses were conducted, considering measurement (4) as a within-subject factor and group (VEG, FEG) and flow level (high or low) as a between-subject factor.

In the **Memory Updating task** the main effect of the **measurement** proved to be significant $F(1, 23) = 6.063$, $p = .022$, $\eta2 = .209$. The other effect proved to be insignificant.

Further analyses revealed that participants were able to significantly increase their accuracy in the fourth measurement (M = 78,622, SD = 8,631) in comparison to the first one (M = 72,754, SD = 11,338).

In order to test whether game training affects accuracy in memory updating during task performance, and what relationship there is to the level of mean flow or individual flow dimensions, a multivariate analysis of variance with repeated measures was conducted. The extrinsic factor was group (VEG, FEG) and the level of average flow (High, Low). The within-subject factor measured at 4 levels was accuracy level (4 measurements: T0, T1, T2, T3). The dependent variable was mean accuracy in memory updating.

Mean Flow Level. Fixed Environment Group (FEG)

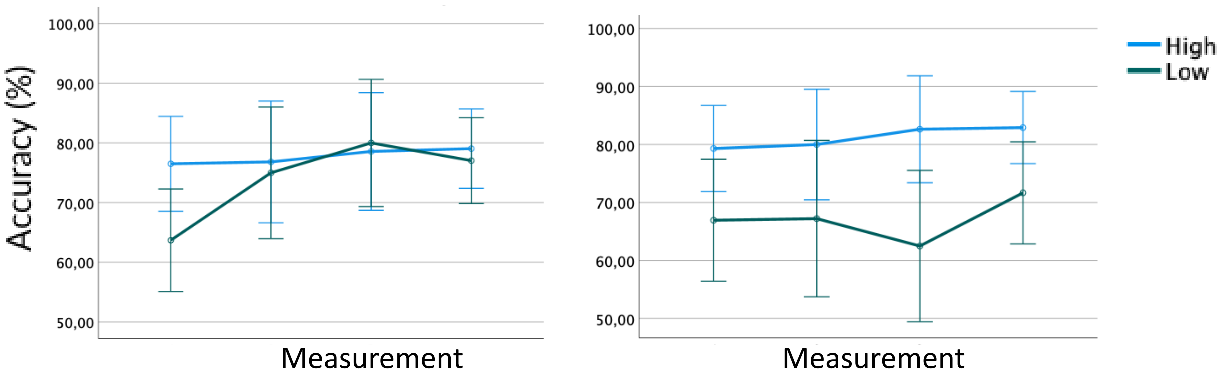


Figure 18. Memory Updating accuracy as a function of Mean Flow Level (High vs Low), group (FEG vs VEG) and measurement point

Significant differences were observed: **measurement main effect**: F(3, 19) = 5.352, p = .008, η2 = .458, and **measurement - group - flow interaction effect**: F(3, 19) = 2.582, p = .084, η2 = .290. In the VEG group, subjects with lower mean flow had a significantly lower mean accuracy result in the first measurement (M = 63.7) than in the second (M = 75.0), third (M = 80.0) and fourth measurement (M = 77.04). In the FEG group, subjects with lower mean flow had a significantly lower mean accuracy result in the third (M = 62.5) than in the fourth measurement (M = 71.67).

For mean Flow Level, a significant result was observed only in the FEG group. Those with a high average flow level slightly but successfully improved their score from measurement to measurement. That is, despite the uninteresting game environment, they were still able to improve their score. Those with a low average flow level decreased their response accuracy between measurements two and three. In their case, the combination of a static game environment and a low average flow level had the effect of worsening their scores, except for the final measurement four, when the score increases. This can be linked to the end-of-task effect, which can also be observed in subsequent analyses. Of note here is the discrepancy in the results from the first measurement in both groups. It can be seen that those with higher flow had higher accuracy levels than those with lower average flow.

H.3.1.b The level of accuracy in memory updating task during the learning process of a complex skill varies - in each flow dimension - depending on the level the participant recorded in a given dimension when measured during the game.

The next step was an analogous process for each of the 9 flow state dimensions. In order to test whether the amount of game training (measurements), its quality (groups) in the group with a higher/ lower level of **flow dimension** affects the **accuracy** in memory updating task, ANOVA analyses were conducted for each of the 9 flow dimensions, treating measurement (4) as a within-subject factor, taking flow level (high or low) and group (VEG, FEG) as a between-subject factors.

Table 34. Results of ANOVA analysis for flow dimensions in Memory Updating task

Memory Updating					
dimension	**effect**	**F**	**df**	**significance**	**η2**
Challenge-skill balance (1)	measurement	**3.363**	3,19	0.040	.347
Merging of action and awareness (2)		**3.688**	3,19	0.030	.368
Clear goals (3)		**3.888**	3,19	0.025	.380
Unambiguous feedback (4)		**4.078**	3,19	0.022	.392
Focus on the task at hand (5)		**4.322**	3,19	0.018	.406
Sense of control (6)	**measurement,**	**4.778**	3,19	0.012	.430
	group and Level Sense of Control interaction	**3.215**	3,19	0.046	.337
Loss of Self-Consciousness (7)	measurement	**3.503**	3,19	0.036	.356
Transformation of time (8)		**4.241**	3,19	0.019	.401
Autotelic experience (9)		**3.737**	3,19	0.029	.371

For the first dimension - **Challenge-Skill Balance** - a **main effect of measurement** was observed F(3, 19) = 3.363, p = .040, η2 =.347. In the **VEG group**, subjects with **lower** level of **Challenge-Skill Balance** had a significantly **lower** mean accuracy result in the first measurement (M = 67.28) than in the second (M = 74.32), third (M = 79.01) and fourth measurement (M = 76.66). There were no other effects in the VEG group, nor any effects in the FEG group.

In the case of dimension two - **Merging of Action and Awareness** - a **main effect of measurement** was observed F(3, 19) = 3.688, p = .030, η2 = .368. In the **VEG group**, subjects with **lower** level of **Merging of Action and Awareness** dimension had a significantly lower mean accuracy result in the first measurement (M = 68.75) than in the second (M = 77.36), third (M = 81.25) and fourth measurement (M = 78.75).

For the third dimension - **Clear Goals** - a **main effect of measurement** was also observed in the **VEG group** with **higher** level of **Clear Goals** dimension F(3, 19) = 3.888, p = .025, η2 = .380, but this occurred only between first measurement (M = 67.77) and the significantly higher fourth measurement (M= 75.71).

Similarly in the fourth dimension - **Unambiguous Feedback** - a **main effect of measurement** was observed in the **VEG** group in subjects with **higher** level of **Unambiguous Feedback** dimension F(3, 19) = 4.078, p = .022, η2 = .392. They had a significantly **lower** average accuracy score on the first measurement (M = 68.88) than on the third (M = 81.58) and fourth (M = 79.04), as well as between the second (M = 75.55) and third measurements.

In dimension fifth - **Focus on the Task at Hand** - we observe a **main effect of measurement** in both the VEG and FEG groups: F(3, 19) = 4.322, p = .018, η2 = .406. Interestingly, in the **VEG** group, the effect applies to those with **higher**, and in the **FEG** group, those with **lower** levels in the **Focus on the Task at Hand** dimension. In the **VEG group**, subjects with **higher** levels of dimension had a significantly **lower** mean accuracy result in the first measurement (M = 67.5) than third (M = 77.36) and fourth measurement (M = 76.38). On the other hand, in the **FEG** group subjects with **lower** level of dimension had a significantly **lower** mean accuracy result in the third measurement (M = 65.77) than fourth measurement (M = 74.22).

Sense of Control (6)

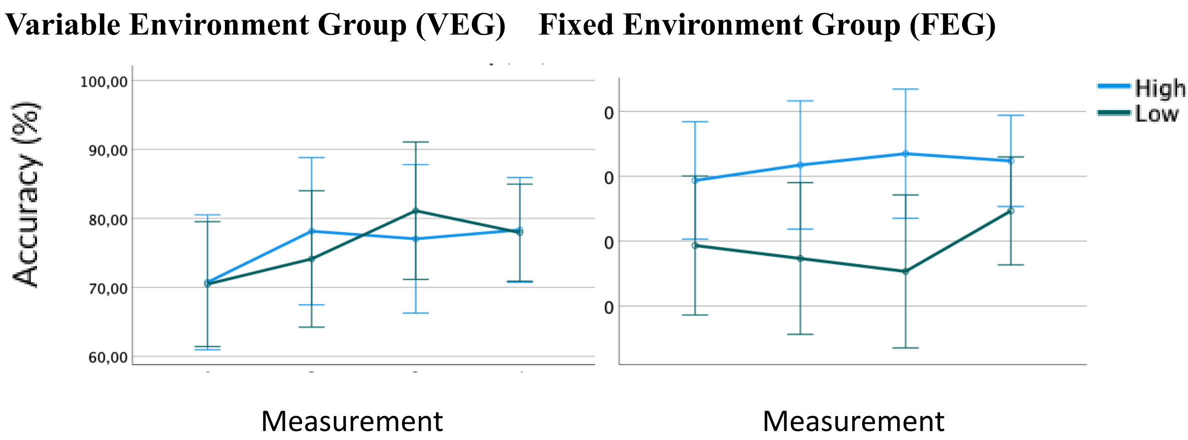


Figure 19. Memory Updating accuracy as a fucntion of Sense of Control dimension (High vs. Low), group (FEG vs VEG) and measurement point

In the case of the sixth dimension - **Sense of Control** - not only the **main measurement effect** was observed F(3, 19) = 4.778, p = .012, η2 =.430, but also the **interaction effect** between **measurement, group** and **level of Sense of Control**: F(3, 19) = 3.215, p = .046, η2 = 337. In **VEG** subjects with **higher** levels of **Sense of Control** had a significantly **lower** mean accuracy result in the first (M = 70.74) than in the fourth measurement (M = 78.33). Subjects with **lower** levels of **Sense of Control** had a significantly **lower** mean accuracy result in first (M = 70.47), than in third (M = 81.11) and fourth measurement (M = 77.93), and also in second (M = 74.13) than third measurement. In **FEG** those who had **lower** levels of **Sense of Control** had significantly lower mean accuracy results in the second (M = 67.33) and in the third (M = 65.33) in comparison to the fourth measurement (M = 74.66).

The results show the influence of the perceived Sense of Control on the change in accuracy during training. Larger changes are observed in the FEG group. Subjects who were subjected to less complex training, and who at the same time indicated a lower sense of sense of control from the beginning, were not able to adequately improve cognitive function with training. By the 3rd measurement, we observe a decline in accuracy. The fourth measurement may represent the effect of the end of the study, as further discussed in the discussion.

As with average flow, it can be seen that those with higher flow had higher levels of accuracy than those with lower average flow.

In the seventh dimension - **Loss of Self-Consciousness** - a **main effect of measurement** was observed F(3, 19) = 3.503, p = .036, η2 =.356. In the **VEG group**, subjects with **lower** level of **Loss of Self-Consciousness** dimension had a significantly **lower** mean accuracy result in the first measurement (M = M= 69.5) than in the second (M = 77.77), third (M = 81.23) and fourth measurement (M = 79.5).

In the case of the eighth dimension - **Time Transformation** - the effect of the main measurement, F(3, 19) = 4.241, p = 0.019, η2 =.401, can be observed again in both groups - **VEG** and **FEG.** The same for those people who are **lower** level in the **Time Transformation** dimension. In the **VEG** group, these subjects had a significantly **lower** average accuracy score in the first measurement (M = 65.71) than in the third (M = 77.14) and fourth measurement (M = 74, 76). In the **FEG**, they had a significantly **lower** average accuracy score in the second (M = 68.7) than in the fourth (M = 75.74) and in third (M = 67.59) than in the fourth measurement.

In dimension ninth - **Autotelic Experience** - we observe a **main effect of measurement** in both the VEG and FEG groups: F(3, 19) = 3.737, p = .029, η2 =.371. Here, as in the fifth dimension, in the **VEG** group, the effect applies to those with **higher**, and those with **lower** levels in the **Autotelic Experience** dimension. Subjects with **higher** levels of dimension had a significantly lower mean accuracy result in the first measurement (M = 68.7) than third (M = 78.33) and also in the second measurement (M = 70.92) than in third. Subjects with **lower** levels of dimension had a significantly lower mean accuracy result in the first measurement (M = 72.22) than second (M = 80.0) and fourth measurement (M = 80.16).

Task Switching

H.3.2.a The cost of switching attention during the process of learning a complex skill varies according to the mean level of flow the participant reported when measured during the game.

Analogous to the previous task, to test whether the cost of switching attention during the learning process of a complex skill varies according to the average flow level the participant reported when measured during the game ANOVA analyses were conducted, considering **measurement** (4) as a within-subject factor and **group** (VEG, FEG) and **flow level** (high or low) as a between-subject factor.

In **Task Switching** in **global - local** condition the **main effect** of the **measurement** proved to be significant F(3, 19) = 2.828, p = .066, η2 = .309. Analyses revealed that in **VEG** participants with **higher levels of mean flow** were able to significantly decrease their **switching cost in global - local conditions** in the fourth measurement (M = 26.33) in comparison to the first one (M = 30.14) and second one (M = 28.75). The remaining effects in the global - local condition found to be insignificant. The results of 25 subjects were included in the calculations (N = 25).

Mean Flow. Variable Environment Group (VEG)

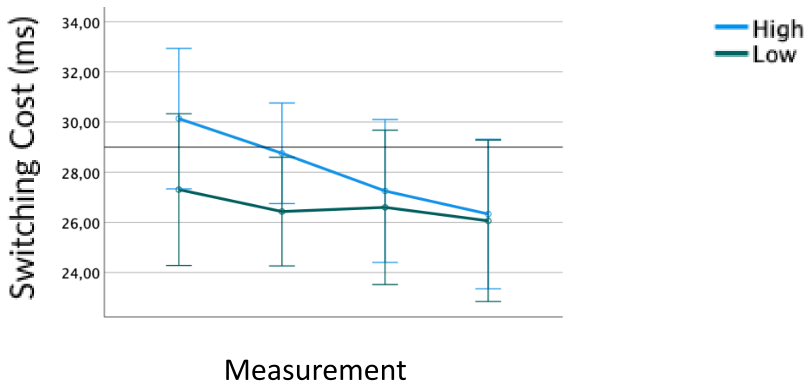


Figure 20. Task Switching cost in local - global condition as a function of Mean Flow (High vs. Low), group (FEG vs VEG) and measurement point

In **Task Switching** in **local - global** condition the **measurement - group interaction effect** proved to be significant $F(3, 19) = 2.305$, $p = .109$, $\eta2 = .267$. Analyses revealed that in **VEG** participants with **higher levels of mean flow** were able to significantly decrease their **switching cost in local - global condition** in the fourth measurement (M = 26.33) in comparison to the first one (M = 30.14) and second one (M = 28.75). The remaining effects in the local - global condition were found to be insignificant. The results of 25 subjects were included in the calculations (N = 25).

For **mean Flow Level** in **local - global** condition, a significant result was observed only in the **VEG**. Those with a high average Flow Level successively but slightly improved their score from measurement to measurement - the cost of switching decreased. Those with a low average flow level also improved their score, but to a significantly lesser extent.

Of note here is the discrepancy in the results from the first measurement in both groups. It can be seen that those with higher flow had higher switching costs than those with lower flow levels.

H.3.2.b The cost of switching attention during the learning process of a complex skill varies - in each flow dimension - depending on the level the participant reported in a given dimension when measured during the game.

In the next step in order to test whether the amount of game training (measurements), its quality (groups) in the group with a higher/ lower level of flow dimension affects the level of switching costs in two conditions (global and local), ANOVA analyses were conducted for each of the 9 flow dimensions, treating **measurement** (4) as a within-subject factor, taking as a between-subject factor: **flow dimension level** (high or low) and **group** (VEG, FEG).

Global - Local Condition

In the global - local condition, the discrepancy in switching costs in the first measurement between VEG and FEG participants is noteworthy. Those in the VEG group perform worse in the first measurement regardless of dimension.

In **Task Switching in global-local** condition tasks in every dimension the main effect of the **measurement** proved to be significant. The detailed results are presented in Table 35.

Table 35. Effects in flow dimensions in the global - local condition

Task Switching (global)					
dimension	**effect**	**F**	**df**	**significance**	**η2**
Challenge-skill balance (1)	measurement	3.235	3,19	0.045	.338
Merging of action and awareness (2)	measurement	2.963	3,19	0.058	.319
Clear goals (3)	measurement	3.663	3,19	0.031	.366
Unambiguous feedback (4)	measurement	4.416	3,19	0.016	.411
	measurement group Unambiguous Feedback interaction	3.476	3,19	0.036	.354
Focus on the task at hand (5)	measurement	4.142	3,19	0.020	.395
Sense of control (6)	measurement	4.355	3,19	0.041	.346
	measurement group Sense of Control interaction	2.349	3,19	0.105	.271
Loss of Self-Consciousness (7)	measurement	3.783	3.19	0.028	.374
	measurement	3.042	3,19	0.054	.325
	measurement	5.390	3,19	0.007	.460
Transformation of time (8)	**measurement Autotelic Experience interaction**	3.745	3,19	0.029	.372
Autotelic experience (9)	**measurement group Autotelic Experience interaction**	4.401	3,19	0.016	.410

In the **global - local** condition in the **Task Switching**, in addition to the ever-present **main effect of measurement** and the **interaction effects** of **measurement** and **flow dimension** were observed: **Unambiguous Feedback**, **Sense of control** and **Autotelic Experience**. Moreover, three-factor interaction effects were observed: **measurement - Autotelic Experience - group interaction effect** and **measurement - group - Sense of Control interaction effect**.

For the first dimension - **Challenge-Skill Balance** - a **main effect of measurement** was observed: F(3, 19) = 3.235, p = .045, η2 =.338. In the **VEG group**, in subjects with **lower** level of **Challenge-Skill Balance** the cost of switching has decreased between first measurement (M = 29.7) and fourth measurement (M = 26.78). There were no other effects in the VEG group, nor any effects in the FEG group.

In the second dimension - **Merging of action and awareness** - we observe a **main effect of measurement:** F(3, 19) = 2.963, p = .058, η2 =.319 in both the VEG and FEG groups. Interestingly, in the **VEG** group, the effect applies to those with **higher**, and in the **FEG** group, those with **lower** levels in the **Merging of action and awareness** dimension. In the **VEG**, in subjects with **higher** levels of **Merging of action and awareness** dimension the cost of switching has **decreased** between the first measurement (M = 30.8) than third (M = 26.76) and fourth measurement (M = 26.39). In contrast, in the **FEG** , a significant **increase** in the cost of switching between the second (M = 28.54) and third (M = 30.34) measurements was observed in those with lower dimension levels.

For the third dimension - **Clear Goals** - a **main effect of measurement** was also observed in the **VEG group** with **higher** level of **Clear Goals** dimension: F(3, 19) = 3.663, p = .031, η2 =.366, the cost of switching has **decreased** between first measurement (M = 29.05), and third (M = 26.15) and fourth (M = 25.92) measurement.

Level of Unambiguous Feedback (4). Variable Environment Group (VEG)

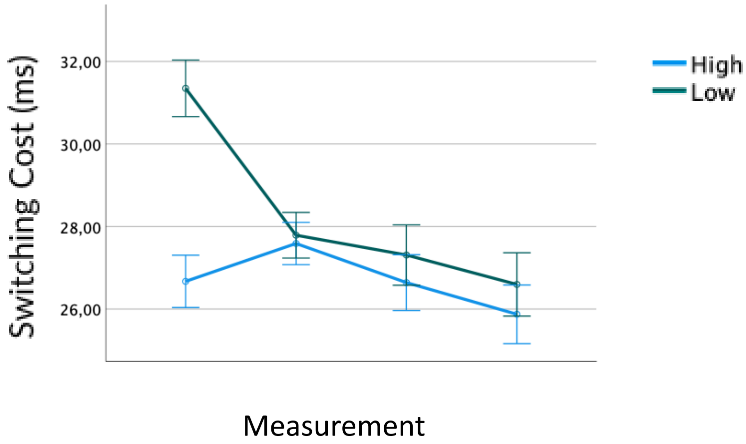


Figure 21. Task Switching cost in global - local condition as a function of Unambiguous Feedback dimension (High vs. Low), group (FEG vs VEG) and measurement point

For a change in the fourth dimension - **Unambiguous Feedback** - a **main effect of measurement:** F(3, 19) = 4.416, p = .016, η2 =.411 and **measurement - group - Unambiguous Feedback interaction effect:** F(3,19) = 3.476, p = .036, η2 = .354 were observed in the **VEG** group in subjects with **lower** level of **Unambiguous Feedback** dimension. Their cost of switching has **decreased** between the first measurement (M = 31.35) and the second (M = 27.8), third (M = 27.31) and fourth (M = 26.6) measurement.

For the mean level of the Unambiguous Feedback dimension (4), a significant result was observed only in the VEG group. In those with a high average level in the Unambiguous Feedback dimension (4), between the first and second measurements, the cost of switching increased, while from the second to the fourth measurement, their results decreased and were analogous to those of the group with a low score. Those with a low average level in the Unambiguous Feedback dimension (4) significantly improved their score, especially between the first and second measurements.

Of note here is the discrepancy in the results from the first measurement in both groups. It can be seen that those with higher levels in the Unambiguous Feedback dimension (4) had lower switching costs than those with lower levels in dimension 4.

In the fifth dimension - **Focus on the Task at Hand** - we observe a **main effect of measurement:** F(3, 19) = 4.142, p = .020, η2 =.395 in both the VEG and FEG groups. Interestingly, in the **VEG** group, the effect applies to those with **higher**, and in the **FEG** group, those with **lower** levels in the **Focus on the Task at Hand** dimension. In the **VEG group** in subjects with **higher** levels of dimension the cost of switching has **decreased** between first measurement (M = 29.17) and third (M = 26.4) and fourth measurement (M = 25.73). On the other hand, in the **FEG** group in subjects with **lower** level of dimension the cost of switching has **increased** between first measurement (M = 27.33) and third (M = 31.81) and fourth (M = 31.85) measurement, and also between second (M = 29.53) and third measurement.

Level of Sense of Control (6)

Variable Environment Group (VEG) | **Fixed Environment Group (FEG)**

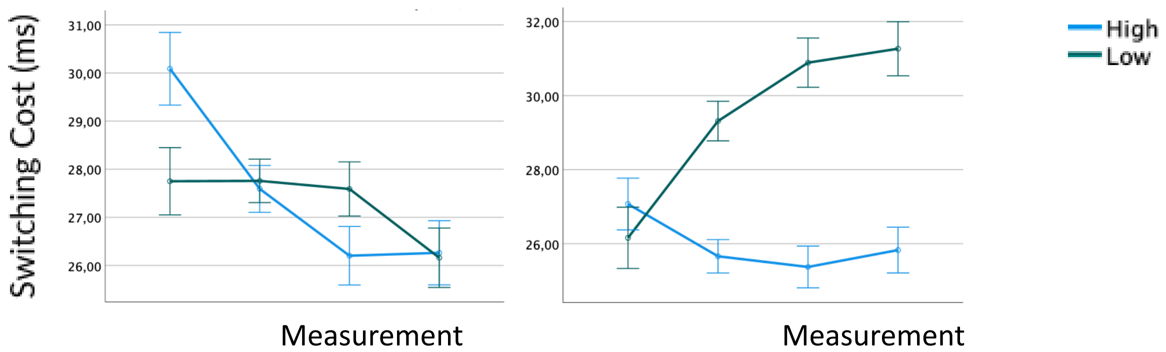


Figure 22. Task Switching cost in global - local condition as a function of Sense of Control dimension (High vs. Low), group (FEG vs VEG) and measurement point.

In the case of the sixth dimension - Sense of Control - not only the **main measurement effect** was observed: F(3, 19) = 4.355, p = .041, η2 =.346, but also the **interaction effect** between **measurement - group - level of Sense of Control**: F(3,19) = 2.349, p = .105, η2 =.271. In **VEG** subjects with **higher** levels of **Sense of Control** the cost of switching has **decreased** between the first measurement (M = 30.1) and third (M = 26.2) and fourth (M = 26.3) measurement. In **FEG** those who had **lower** levels of **Sense of Control** the cost of switching has **increased** between the first measurement (M = 26.16) and the second (M = 29.31), third (M = 30.9) and fourth (M =31.27) measurement.

For the mean level of the Sense of Control dimension (6), a significant result was observed in both groups: VEG and FEG. In VEG, in subjects with a high average level in the Sense of Control dimension (6), the switching cost decreased, especially between the first and second measurements. In those with a low average level in the Sense of Control dimension (6), the switching score also decreased, with different dynamics - minimal differences by the third measurement, and a significant decrease in measure 3.

Attention is again drawn to the discrepancy in the results from the first measurement in both groups. It can be seen that those with higher levels in the Sense of Control dimension (6) had higher switching costs than those with lower levels in dimension 6.

A different dynamic is observed for FEG, where both groups (those with higher and lower scores on the Sense of Control measure) have similar scores on the first dimension (although still the group with the higher score starts with a slightly higher switching cost. Here, the group with the higher Sense of Control (6) successively decreases the switching cost (up to the 3rd measurement), while in the group with the lower Sense of Control (6) this score increases dramatically. Thus, the FEG group, i.e., those who work in a static environment that does not provide challenges, and on top of that have a lower level of flow, are doing worse and worse from measurement to measurement.

In the seventh dimension - **Loss of Self-Consciousness** - we observe a **main effect of measurement:** $F(3, 19) = 3.783$, $p = .028$, $\eta 2 = .374$ in both the **VEG** and **FEG** groups. Interestingly, in the **VEG** group, the effect applies to those with **higher**, and in the **FEG** group, those with **lower** levels in the **Loss of Self-Consciousness** dimension. In the **VEG group** in subjects with **higher** levels of dimension the cost of switching has **decreased** between the first measurement (M = 30.92) and third (M = 26.73) and fourth (M = 26.8) measurement. On the other hand, in the **FEG** group in subjects with **lower** level of dimension the cost of switching has **increased** between the first measurement (M = 26.2) and third (M = 30.69) and fourth (M = 31.3) measurement.

In the eighth dimension, also observed a main effect of measurement**:** $F(3,19) = 3.042$, $p = .054$, $\eta 2 = .325$ in the **VEG** and **FEG** groups, but in this case, in both groups, it is in individuals who have **lower** scores in the **Transformation of Time** dimension. In the **VEG group** in subjects with **lower** levels of dimension the cost of switching has **decreased** between first measurement (M = 27.92) and fourth (M = 24.7) and also between second (M=27.5) and fourth measurement. Whereas in the **FEG** group in subjects with **lower** level of dimension the cost of switching has **increased** between first (M = 27.03) and fourth measurement (M = 30.0) and also between second (M = 28.8) and fourth measurement.

Level of Autotelic Experience (9)

Variable Environment Group (VEG) | **Fixed Environment Group (FEG)**

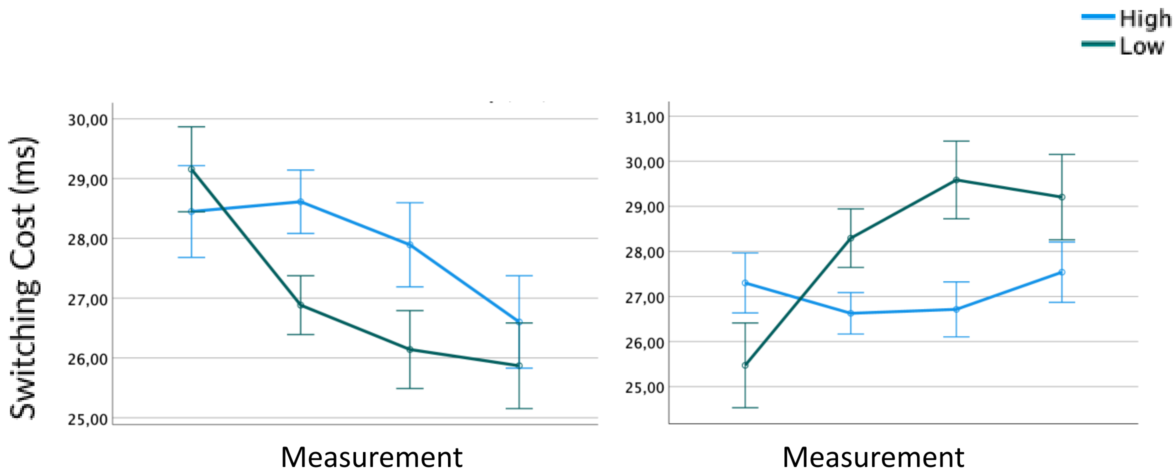


Figure 23. Task Switching cost in global - local condition as a function of Autotelic Experience dimension (High vs. Low), group (FEG vs VEG) and measurement point

In the last ninth dimension - **Autotelic Experience** - observed a **main effect of measurement**: F(3, 19) = 5.390, p = .007, η2 = .460, **measurement Autotelic Experience interaction effect:** F(3, 19) = 3.745, p = .029, η2 = .372 and **measurement group Autotelic Experience interaction effect:** F(3, 19) = 4.401, p = .016, η2 =.410. In both groups the effect applies to those with **lower** levels in the **Autotelic Experience** dimension. In the **VEG** the cost of switching has **decreased** between the first measurement (M = 29.16) with the third (M = 26.14) and fourth (M = 25.9) measurement. On the other hand, in the **FEG** the cost of switching has **increased** between the first measurement (M = 25.47) and third (M = 29.59) measurement.

In the Autotelic Experience dimension (9), a significant result was observed in both groups: VEG and FEG. In VEG, in all participants with a high average level in the Autotelic

Experience dimension (9), the cost of switching decreased, differing in dynamics, especially between the first and second measurements. A resurgent trend is observed in the FEG group, where those with a high Autotelic Experience score (9) return to their starting point after a slight improvement, while those with a low score on the Autotelic Experience dimension (9) raise their switching cost.

Of note are the results in both groups, where in the VEG group those with a higher average flow have a better score at the start, while in the VEG group we see the opposite situation.

Local - Global Condition

In the **local-global** condition, the main effect of measurement was not observed, while **measurement-group** and **measurement-flow dimension** interaction effects appeared. The detailed results are presented in Table No. 36. And so these are mainly **measurement** and **group interactions** or **measurement** and **flow dimension** or three-factor **interactions**: **Merging of Action and Awareness**, **Focus on the Task at Hand**, **Sense of Control**, **Loss of Self-Consciousness** and **Transformation of Time**.

Table 36. Effects in flow dimensions in the local - global condition

dimension	effect	F	df	significance	η2
Challenge-skill balance (1)	-				
Merging of action and awareness (2)	**measurement Merging of Action and Awareness**	4.025	3,19	0.023	.389
	measurement*group	3.098		0.051	.328
Clear goals (3)	measurement group	2.790	1, 21	0.068	.306
Unambiguous feedback (4)	measurement group	3.069	3,19	0.053	.326
Focus on the task at hand (5)	**measurement*Focus on the Task at Hand**	6.219	3,19	0.004	.495
	measurement*group	4.913	3,19	0.011	.437
Sense of control (6)	**measurement*Sense of control**	7.645		0.002	.547
	measurement*group	6.067	3.19	0.004	.489
Loss of Self-Consciousness (7)	**measurement*Loss of Self-Consciousness**	3.345		0.041	.346
	measurement*group	5.281	3.19	0.008	.455
Transformation of time (8)	**measurement*group * Transformation of Time**	2.944		0.059	.317
	measurement*group	3.328	3,19	0.042	.344
Autotelic experience (9)	measurement*group	3.203	3,19	0.047	.336

In the local - global condition, the discrepancy in switching costs in the first measurement between VEG and FEG participants is noteworthy. Those in the VEG group perform worse in the first measurement regardless of dimension. No significant effects were observed in the **Challenge - Skill Balance** dimension (1): $F(3, 19) = 1.837$, $p = .175$, $\eta 2 = .225$. In VEG subjects with **lower** level of Challenge - Skill Balance the cost of switching has **decreased** between first (M = 29.7) with fourth (M = 26.78) measurement.

Level of Merging of action and awareness (2)

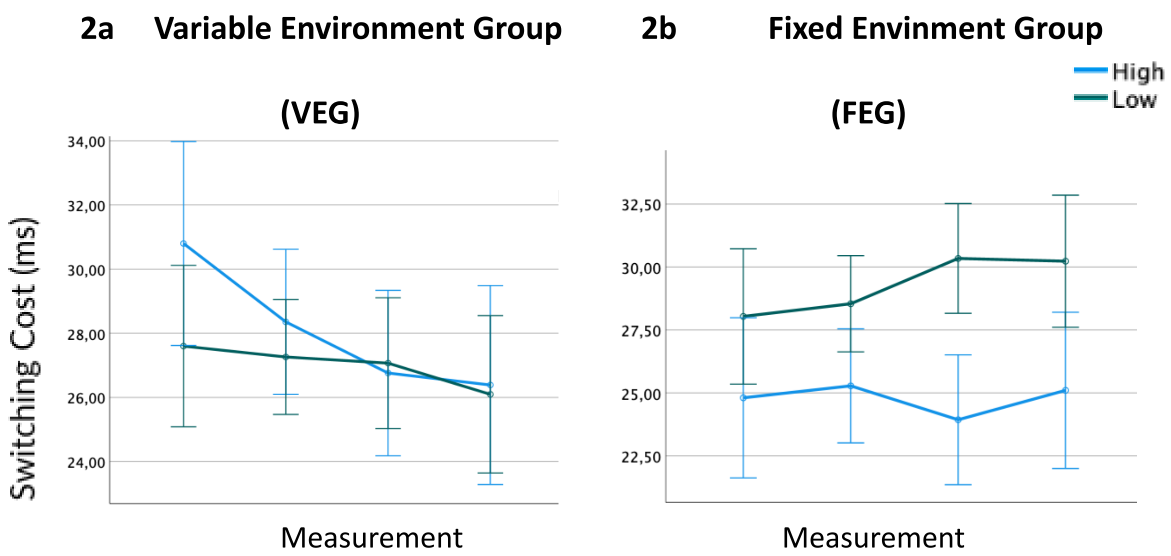


Figure 24. Task Switching cost in local - global condition as a function of Merging of action and awareness dimension (High vs. Low), group (FEG vs VEG) and measurement point

In the second dimension - **Merging of action and awareness** - we observe a **measurement - group interaction effect:** $F(3, 19) = 3.098$, $p = .051$, $\eta 2 = .328$, and also **measurement - Merging of Action and Awareness interaction effect:** $F(3, 19) = 4.025$, $p = .023$, $\eta 2 = .389$. Interestingly, in the **VEG** group, the effect applies to those with **higher**, and in the **FEG** group, those with **lower** levels in the **Merging of action and awareness** dimension. In the **VEG group**, in subjects with **higher** level of dimension the cost of switching has **decreased** between the first (M = 30.8) and third (M = 26.76) and fourth (M = 26.39) measurements. On the other hand, in the **FEG** group in subjects with **lower** level of **Merging of action and awareness** the cost of switching has **increased** between second (M = 28.54) and third (M = 30.34) measurement.

In **local - global conditions**, slightly different relationships are observed. For the **Merging of Action and Awareness** dimension (2), significant results appeared in both **VEG** and **FEG**. In both groups, a large discrepancy is also observed between the first measurements between the group with high and low scores on the dimension. Thus, in VEG, the cost of switching in both groups decreases, adopting very similar dynamics from the 4th measurement onward. In FEG, the switching cost of the group with a higher Merging of Action and Awareness (2) score - remains at a similar level, while the group with a lower score - increases, so participants playing in a fixed environment, perceiving in addition the Merging of Action and Awareness (2) score as low, worsen their performance in terms of switching cost.

In the third dimension - **Clear Goals** - a **measurement group interaction effect** was also observed in the **VEG group** with **higher** level of **Clear Goals** dimension**:** $F(3, 19) = 2.790$, $p = .068$, $\eta2 = .306$. The cost of switching has **decreased** between the first (M = 31.35) and second (M = 27.8), third (M = 27.31) and fourth (M = 26.6) measurement.

Similarly in the fourth dimension - **Unambiguous Feedback** - a **measurement group interaction effect** was observed in the **VEG** with a lower level of **Unambiguous Feedback** dimension**:** $F(3, 19) = 3.069$, $p = 0.053$, $\eta2 = .326$. The cost of switching has **decreased** between the first (M = 31.35) and second (M = 27.8), third (M = 27.31) and fourth (M = 26.6) measurement.

Level of Focus on the Task at Hand (5)

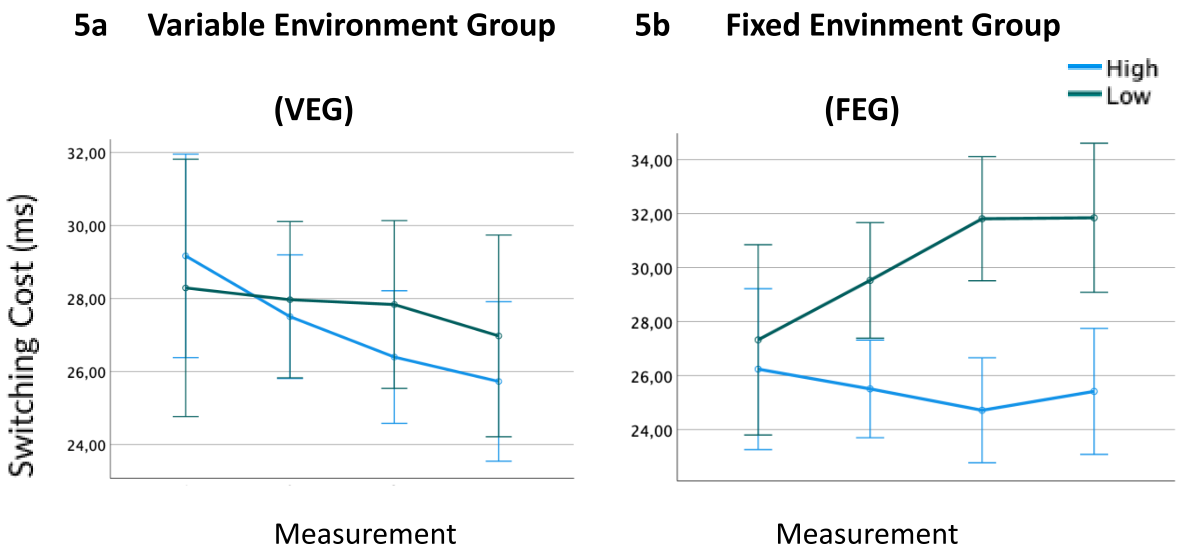


Figure 25. Task Switching cost in local - global condition as a function of Focus on the Task at Hand dimension (High vs. Low), group (FEG vs VEG) and measurement point

In the fifth dimension - **Focus on the Task at Hand** - we observe a **measurement group interaction effect:** F(3, 19) = 4.913, p = .011, η2 =.437 and also **measurement - Focus on the Task at Hand interaction effect:** F(3, 19) = 6.219, p = .004, η2 =.495. Again, in the **VEG** group, the effect applies to those with **higher**, and in the **FEG** group, those with **lower** levels in the **Focus on the Task at Hand** dimension. In the **VEG group**, in subjects with **higher** level of dimension the cost of switching has **decreased** between the first (M = 29.17) and third (M = 26.4) and fourth (M = 25.73) measurements. On the other hand, in the FEG group in subjects with **lower** level of **Focus on the Task at Hand** the cost of switching has **increased** between first (M = 27.33) and third (M = 31.81) and fourth (M = 31.85) measurement, and also between second (M = 29.53) and third measurement.

On the **Focus on the Task at Hand (5)** dimension in the **VEG** group, all participants improve their attentional switching score, while in the **FEG** group, while those with a higher score on Focus on the Task at Hand (5) slightly improve their score, those with a low score on this dimension worsen their score, especially on the second and third measures.

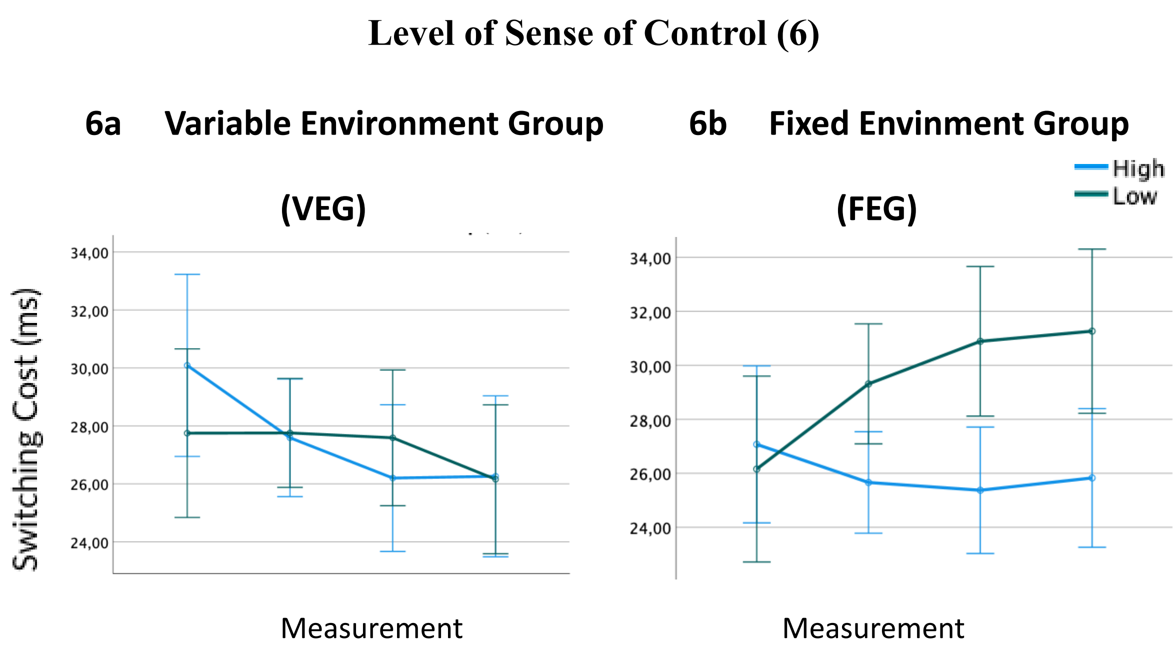


Figure 26. Task Switching cost in local - global condition as a function of Sense of Control dimension (High vs. Low), group (FEG vs VEG) and measurement point

Similarly in the sixth dimension - **Sense of Control** - we observe a **measurement group interaction effect:** F(3, 19) = 6.067, p = .004, η2 =.489 and also **measurement Sense of Control interaction effect:** F(3, 19) = 7.645, p = .002, η2 = .547. Also in this dimension in the **VEG** group, the effect applies to those with **higher**, and in the **FEG** group, those with **lower** levels in the **Sense of Control** dimension. In the **VEG group**, in subjects with **higher** level of dimension the cost of switching has **decreased** between first (M= 30.1) with third (M = 26.2) and fourth (M = 26.26) measurement. Whereas in the **FEG** group in subjects with **lower** level of **Sense of Control** the cost of switching has **increased** between first (M = 26.16) and second (M = 29.31), third (M = 30.9) and fourth (M = 31.27) measurement.

In the Sense of Control dimension (6), correlations analogous to dimension 5 are observed. In the VEG, all participants improve their attentional switching score, while in the FEG group, while those with a higher score in Sense of Control (6) slightly improve their score, those with a low score in this dimension deteriorate significantly.

Level of Loss of Self-Consciousness (7)

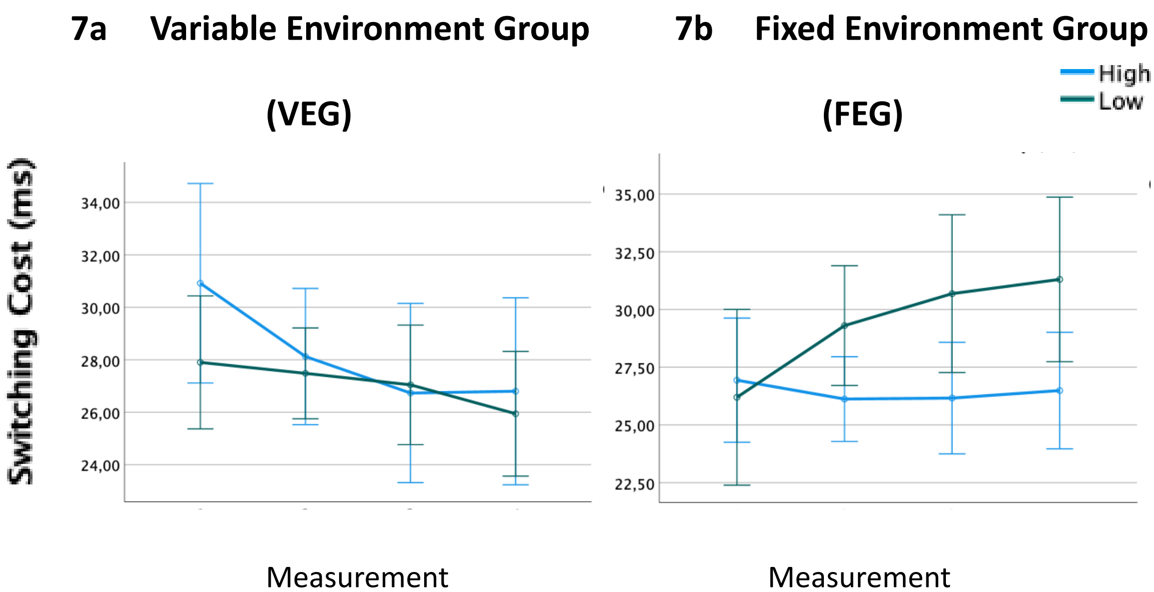


Figure 27. Task Switching cost in local - global condition as a function of Loss of Self-Consciousness dimension (High vs. Low), group (FEG vs VEG) and measurement point

Analogous results were observed in the seventh dimension - **Loss of Self-Consciousness**: **measurement group interaction effect:** F(3, 19) = 5.281, p = .008, η2 =.455 and **measurement Loss of Self-Consciousness interaction effect:** F(3, 19) = 3.345, p = .041, η2 =.346. Also in this dimension in the **VEG** group, the effect applies to those with **higher**, and in the **FEG** group, those with **lower** levels in the **Loss of Self-Consciousness** dimension. In the **VEG group**, in subjects with **higher** level of dimension the cost of switching has **decreased** between first (M = 30.92) with third (M = 26.73) and fourth (M =

26.8) measurement. Whereas in the **FEG** group in subjects with **lower** level of **Loss of Self-Consciousness** the cost of switching has **increased** between first (M = 26.2) with third (M = 30.69) and fourth (M = 31.3) measurement.

In the Loss from Self-Consciousness (7) dimension, correlations analogous to dimensions 5 and 6 are observed. In the VEG, all participants improve their attentional switching score, while in the FEG group, while those with a higher score in Loss from Self-Consciousness (7) do not see much change, those with a low score in this dimension significantly worsen cost switching.

Of note is the discrepancy in switching costs in the first measurement between VEG and FEG participants. Those in the VEG group perform worse in the first measurement.

Level of Transformation of Time (8)

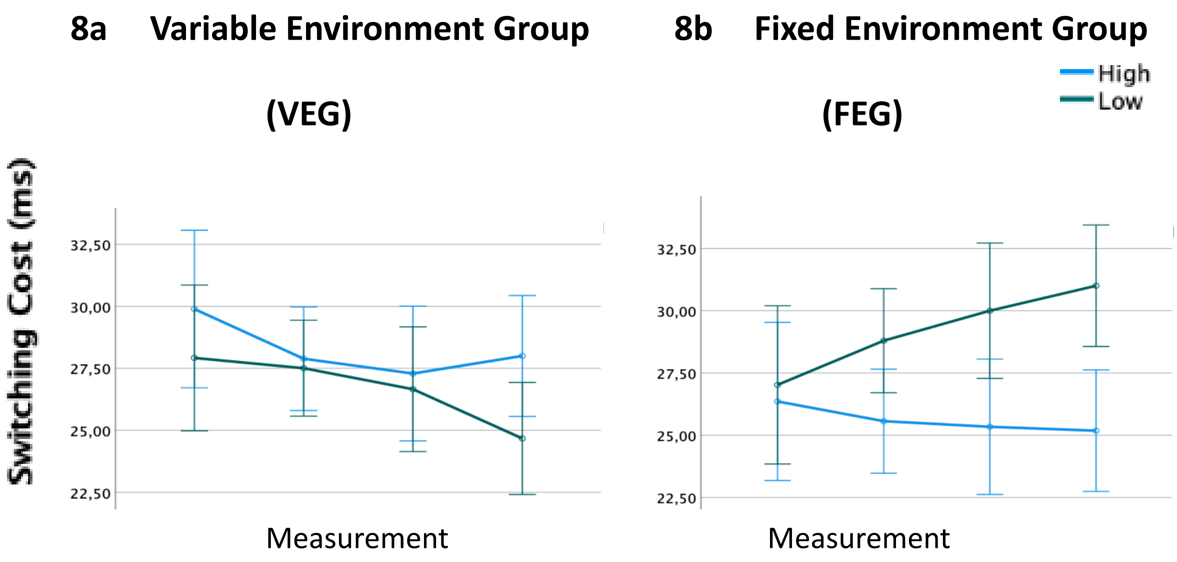


Figure 28. Task Switching cost in local - global condition as a function of Transformation of Time dimension (High vs. Low), group (FEG vs VEG) and measurement point

In the eighth dimension - **Transformation of Time** - similar interactions was observed: **measurement group interaction effect:** $F(3, 19) = 3.328$, $p = .042$, $\eta 2 = .344$ and also **measurement - group - Transformation of Time interaction effect:** $F(3,19) = 2.944$, $p = .059$, $\eta 2 = .317$. In **both** groups, the effect applies to those with **lower** levels in the **Transformation of Time** dimension. In the **VEG group**, in subjects with **lower** levels of dimension the cost of switching has **decreased** between first (M = 27.92) and fourth (M = 24.67) measurement and also between second (M = 27.5) and fourth measurement. Whereas in the **FEG** group in subjects with **lower** levels of **Transformation of Time** the cost of switching has **increased** between first (M = 27.02) with fourth (M = 31.0) measurement, and also between second (M = 28.8) and fourth measurement.

In the Transformation of Time (8) dimension, we have a similar situation to the previous dimensions in the local - global condition. In the VEG, all participants improve their attentional switching score, while in the FEG group, while those with a higher score in Transformation of Time (8) show a slight improvement, those with a low score in this dimension significantly worsen cost switching.

Of note is the discrepancy in switching costs in the first measurement between VEG and FEG participants. Those in the VEG group perform worse in the first measurement.

In the last dimension, **Autotelic Experience**, only the **measurement group interaction effect** was observed**:** $F(3, 19) = 3.203$, $p = 0.047$, $\eta 2 = .336$. In **both** groups, the effect applies to those with **lower** levels in the **Autotelic Experience** dimension. In the **VEG group** the cost of switching has **decreased** between the first (M = 29.16) and third (M = 26.14) and fourth (M = 25.9) measurement. In the **FEG group** the cost of switching has **increased** between first (M = 25.47) and third (M = 31.0) measurement.

Local vs. Global Condition

Here are the conclusions based on the statistical results:

1. Challenge-Skill Balance was not significant in the local measure but was significant in the global measure ($F(3,19) = 3.235$, $p = 0.045$, $\eta^2 = .338$), suggesting that the balance of skill and challenge becomes more relevant in the global context of task switching.
2. Both local and global measures showed some significance in Merging of Action and Awareness dimension. The local measure showed a significant effect of measurement on the group ($F(3,19) = 3.098$, $p = 0.051$, $\eta^2 = .328$) while the global measure was near significance for the overall measurement ($F(3,19) = 2.963$, $p = 0.058$, $\eta^2 = .319$). This suggests the merging of action and awareness affects task switching both locally and globally.
3. In Clear Goals the local measure showed a near significance for the group ($F(1, 21) = 2.790$, $p = 0.068$, $\eta^2 = .306$), while the global measure showed a significant effect ($F(3,19) = 3.663$, $p = 0.031$, $\eta^2 = .366$). This suggests that having clear goals is essential both in the local context of a task and in the broader, global context.

4. Both the local and global measures showed some significance in the Unambiguous Feedback dimension. The local measure was near significant for the group ($F(3,19) = 3.069$, $p = 0.053$, $\eta^2 = .326$), and the global measure showed a significant effect for the measurement and its interaction with the group ($F(3,19) = 4.416$, $p = 0.016$, $\eta^2 = .411$, $F(3,19) = 3.476$, $p = 0.036$, $\eta^2 = .354$). This suggests that the clarity of feedback has a role in both the local and global contexts of task-switching.
5. In Focus on the Task at Hand both local and global measures showed significant effects, but the effect sizes were larger for the local measure ($F(3,19) = 6.219$, $p = 0.004$, $\eta^2 = .495$, $F(3,19) = 4.913$, $p = 0.011$, $\eta^2 = .437$) than for the global measure ($F(3,19) = 4.142$, $p = 0.020$, $\eta^2 = .395$). This suggests that although focusing on the task at hand is crucial in both contexts, it is particularly critical in the local context.
6. Both local and global measures in Sense of Control dimension showed significant effects, with a larger effect size for the local measure ($F(3,19) = 7.645$, $p = 0.002$, $\eta^2 = .547$, $F(3,19) = 6.067$, $p = 0.004$, $\eta^2 = .489$) than for the global measure ($F(3,19) = 4.355$, $p = 0.041$, $\eta^2 = .346$). This indicates that sense of control is vital in both contexts but seems more influential locally.
7. In Loss of Self-Consciousness both local and global measures showed significant effects, with the local measure showing a larger effect size ($F(3.19) = 5.281$, $p = 0.008$, $\eta^2 = .455$) than the global measure ($F(3.19) = 3.783$, $p = 0.028$, $\eta^2 = .374$). This suggests that losing self-consciousness can aid task-switching performance in both contexts, but it might be more influential in the local context.
8. In Transformation of Time dimension the local measure was near significance for the group ($F(3,19) = 3.328$, $p = 0.042$, $\eta^2 = .344$), and the global measure was also near significance ($F(3,19) = 3.042$, $p = 0.054$, $\eta^2 = .325$). This suggests that perception of time transformation may have a similar impact on task-switching in both the local and global contexts.
9. In Autotelic Experience dimension the local measure showed a near significance for the group ($F(3,19) = 3.203$, $p = 0.047$, $\eta^2 = .336$), while the global measure was significant for the measurement and its interaction with the group ($F(3,19) = 5.390$, $p = 0.007$, $\eta^2 = .460$, $F(3,19) = 4.401$, $p = 0.016$, $\eta^2 = .410$). This suggests that experiencing intrinsic reward (autotelic experience) from the task might be more impactful in a global context than in a local one.

Task Switching Results. Summary

In **Task Switching** in **global-local condition** tasks **in every dimension the main effect of the measurement** proved to be significant. Additionally the interaction effects of measurement and flow dimension were observed: **Unambiguous Feedback (4), Sense of control (6)** and **Autotelic Experience (9)**. Moreover, a **three-factor interaction effects** were observed: **measurement - Autotelic Experience (9) - group interaction effect** and **measurement - group - Sense of Control (6) interaction effect**.

In the **local-global condition,** the main effect of measurement was not observed, while **measurement-group interaction effects appeared in all dimensions**, except Challenge - Skill Balance (1). In addition, there are **three-factor interaction effects**: **Merging of Action and Awareness (2), Focus on the Task at Hand (5), Sense of Control (6), Loss of Self-Consciousness (7)** and **Transformation of Time (8)**.

In the Task Switching task, a **recurring pattern was observed in both conditions** (global - local and local - global). In the **VEG**, among participants with **higher** scores in particular dimensions - the **cost of switching decreases.** Among low-scoring participants, such a relationship occurs in only two dimensions in both conditions: Challenge - Skill Balance (1) and Unambiguous Feedback (4), and - only in the global-local condition - in the Autotelic Experience dimension (9). On the other hand, in the **FEG**, there are no significant effects among those with high scores in each dimension, while an **increase in switching cost is observed among those with low scores in the flow dimensions** (except in dimensions 1 and 4).

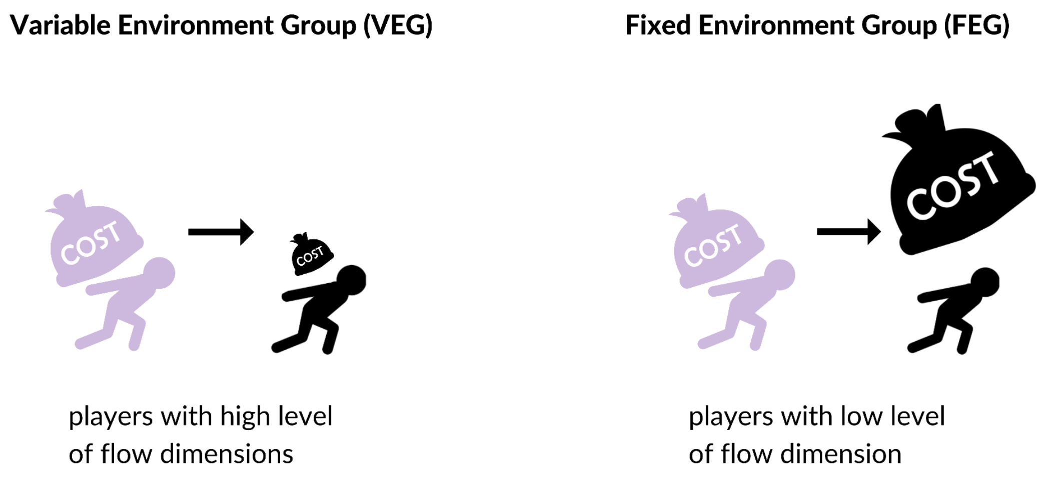


Figure 29. Differences in the significant effects in costs in the Task Switching for two groups: VEG and FEG for subjects with different levels in the flow dimensions, for both conditions together

Visual Motion Direction Discrimination

H.3.3.a The accuracy and reaction time for each level of coherence during the learning process of a complex skill varies according to the mean level of flow the participant recorded during the game measurement. (Visual Motion Direction DIscrimination VMDD, PFSS-2)

In order to test whether the amount of game training - **measurements**, its quality - **groups**, in the group with a higher/ lower **level of flow** affects the level of visual motion direction discrimination, **ANOVA** analyses were conducted for **mean flow**, treating **measurement** (4) as a within-subject factor, and taking as a between-subject factor: **group** (VEG, FEG) and **flow** level (high or low).

Response Accuracy

With regard to the **reaction time** and **accuracy** of the subjects' responses, the reaction times at different levels of **coherence** (1.6%, 3.2%, 6.4%, 12.8%, and 25.6%) were verified. The coherence level has a significant impact on the accuracy and speed of visual motion direction discrimination. Higher coherence levels lead to better discrimination performance, as the direction of motion of the stimulus is more consistent and easier to perceive. Lower coherence levels result in poorer discrimination performance, as the direction of motion is less consistent and harder to perceive.

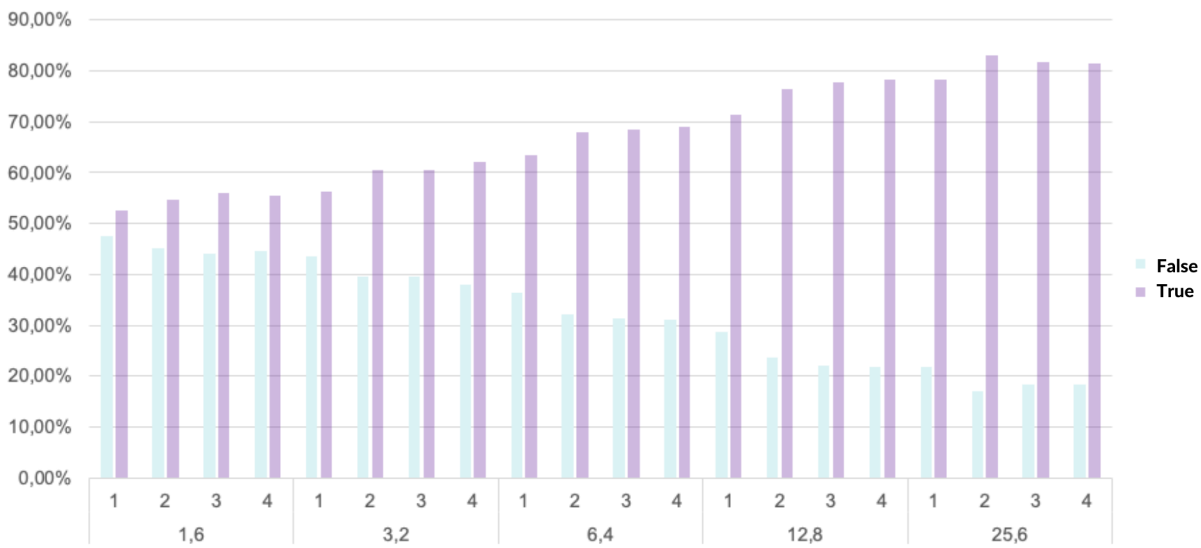


Figure 30. Dynamics of distribution of correct and incorrect answers in 4 measurements at 5 levels of coherence (1.6%, 3.2%, 6.4%, 12.8%, and 25.6%)

As expected, an improvement in accuracy was observed from measurement to measurement, with the number of correct responses at lower levels of coherence being low and increasing in proportion to increasing levels of coherence. (Fig. 28). Since the group - coherence level interaction did not prove significant, we averaged the accuracy of motion discrimination across all five levels of coherence (1.6, 3.2, 6.4, 12.8 and 25.6) and used this data as the dependent variable in further analyses.

In relation to **Flow Mean**, the **main effect of measurement** was observed: $F(3, 21) = 8.676$, $p = <0.001$, $\eta 2 = .553$. In **VEG**, in subjects with **higher** level of **Flow Mean,** level of accuracy **increased** between the first (M = 65.7) and the third measurement (M = 70.67). In **FEG** in subjects with **higher Flow Mean,** mean level of response accuracy **increased** between the first measurement (M = 60.02) and the second (M = 64.77), third (M = 67.84) and fourth measurement (M = 65.86), and also between second and third measurement. In **FEG in** subjects with **lower Flow Mean,** mean level of response accuracy **increased** between the first measurement (M = 62.2) and the second (M = 69.04), third (M = 70.48) and fourth measurement (M = 72.35), and also between second and fourth measurement.

In sum, from measurement to measurement, those with **higher Mean Flow** responded more correctly in both groups - **VEG** and **FEG, but** among those with **lower Mean Flow**, statistically significant improvement was noted only in the **FEG**.

Reaction Time (RT)

Considering **Flow Mean,** the **main effect of measurement** was found to be significant $F(3, 21) = 4.207$, $p = 0.018$, $\eta 2 =.357$. The other effects were found to be insignificant. In the **VEG**, in subjects with **higher mean flow** a mean **reaction time (RT) significantly decreased** between the first measurement (M = 225,05) and the second (M= 202.85), third (M = 194.74) and fourth measurement (M = 197.1). And in subjects with **lower mean flow** a mean **reaction time (RT) significantly decreased** between the the third measurement (M = 205.52) and the fourth measurement (M = 191.06). In **FEG**, in subjects with **higher mean flow** a mean **reaction time (RT) significantly decreased** between the first measurement (M = 249.25) and the second (M = 210.11), third (M = 205.78) and fourth measurement (M = 207.4).

Thus, from measure to measure, the reaction time of those with **higher Mean Flow** took **less time to respond** in both groups - **VEG** and **FEG**. Among those with **lower Mean Flow**, a statistically significant improvement was seen only in the **VEG**. Overall, these findings suggest that measurement had a significant impact on the reaction times of the subjects, particularly in those with higher mean flow.

H.3.3.b The accuracy and reaction time for each level of coherence during the learning process of a complex skill varies according to level of each from flow dimensions, the participant recorded during the game measurement. (Visual Motion Direction Discrimination VMDD, PFSS-2)

In order to test whether the amount of game training - **measurements**, its quality - **groups**, in the group with a higher/ lower **level of every flow dimension** affects the **response time** in **visual motion direction discrimination**, ANOVA analyses were conducted for dimension of flow, treating measurement (4) as a within-subject factor, and taking as a between-subject factor: **group** (VEG, FEG) and **dimension of flow level** (high or low).

Reaction Time in VMDD

In Reaction Time (RT) in **VMDD** in every dimension the main effect of the **measurement** proved to be significant. The detailed results are presented in Table 37.

Table 37. Reaction Time (ms) in Visual Motion Direction Discrimination. Measurement effect

dimension	F	df	significance	η2
Mean Flow	4.207	3,21	0.018	.357
Challenge-skill balance (1)	4.237	3,21	0.017	.377
Merging of action and awareness (2)	5.247	3,21	0.007	.428
Clear goals (3)	5.418	3,21	0.006	.436
Unambiguous feedback (4)	4.895	3,21	0.010	.411
Focus on the task at hand (5)	5.085	3,21	0.008	.421
Sense of control (6)	4.769	3,21	0.011	.405
Loss of Self-Consciousness (7)	5.422	3,21	0.006	.436
Transformation of time (8)	5.409	3,21	0.006	.436
Autotelic experience (9)	4.888	3,21	0.010	.411

In dimension **Challenge-Skill Balance** (1) - a **main effect of measurement** was observed: $F(3, 21) = 4.237$, $p = .017$, $\eta2 = .377$. In **VEG**, in subjects with **lower** level of **Challenge-Skill Balance** dimension, the level of **reaction time decreased** between the first measurement (M = 214.12) and the fourth measurement (M = 190.5). In **FEG** in subjects with **higher Challenge-Skill Balance** dimension, mean **reaction time decreased** between the first measurement (M = 248.02) and the second (M = 206.4), third (M = 208.91) and fourth measurement (M = 203.43). There were no other effects in the VEG group, nor any effects in the FEG group.

For **Merging of Action and Awareness** (2) - a **main effect of measurement** was observed: F(3, 21) = 5.247 p = .007, η2 =.428. In **FEG** in subjects with **higher** level of **Merging of Action and Awareness** dimension, mean **reaction time decreased** between the first measurement (M = 248.02) and the second (M = 206.4), third (M = 208.91) and fourth measurement (M = 203.43). In subjects with **lower Merging of Action and Awareness** dimensions, mean **reaction time decreased** between the first (M = 238.68) and second (M = 209.86) and fourth measurement (M = 208.5).

The situation is slightly different in terms of **Clear Goals** dimension (3) - although the main **effect of measurement** was observed: F(3, 21) = 5.418 p = .006, η2 =.436, it applies to both groups **VEG** and **FEG.** In subjects with **higher levels of Clear Goals** dimension, mean **reaction time decreased** between the first measurement (M = 215.4) and fourth measurement (M = 187.45). In FEG in subjects with **higher levels of Clear Goals** dimension, mean **reaction time decreased** between the first (M = 248.02) and second (M = 203.5), third (M = 195.2) and fourth measurement (M = 200.51).

Otherwise in the Unambiguous **Feedback** (4) dimension - a **main effect of measurement** was observed: F(3, 21) = 4.895 p = .010, η2 =.411, but in **FEG** only in subjects with **lower** levels of **Unambiguous Feedback.** Mean **reaction time decreased** between the first measurement (M = 240.64) and second (M = 205.05), third (M = 193.7) and fourth measurement (M = 201.24).

In **Focus on the Task at Hand** (5), like in the third dimension - a **main effect of measurement** was observed: F(3,21) = 5.085 p = 0.008, η2 =.421. In **FEG** in subjects with **higher** level of **Focus on the Task at Hand** dimension, mean **reaction time decreased** between the first measurement (M = 239.55) and second (M = 211.7), third (M = 201.9) and fourth measurement (M = 204.86). In subjects with **lower** level of **Focus on the Task at Hand** dimension mean **reaction time decreased** between the first measurement (M = 237.6) and second measurement (M = 204.02).

In **Sense of Control** (6) dimension - a **main effect of measurement** was observed: F(3, 21) = 4.769 p = .011, η2 =.405. In **FEG** in subjects with **higher** level of **Sense of**

Control dimension mean **reaction time decreased** between the first measurement (M = 237.2) and second (M = 201.5), third (M = 201.94) and fourth measurement (M = 199.77).

In **Loss of Self - Consciousness** (7) dimension - a **main effect of measuremen**t was observed: F(3, 21) = 5.422 p = .006, η2 =.436. In **FEG** in subjects with **higher** level of **Loss of Self - Consciousness** mean **reaction time decreased** between the first measurement (M = 239.07) and second (M = 213.93), third (M = 203.48) and fourth measurement (M = 204.85). In subjects with **lower** level of **Loss of Self - Consciousness** dimension mean **reaction time decreased** between the first measurement (M = 238.21) and second measurement (M = 197.07).

In **Transformation of Time** (8) dimension - a **main effect of measurement** was observed: F(3, 21) = 5.409 p = .006, η2 =.436. In **VEG** in subjects with **higher** level of **Transformation of Time, mean reaction time decreased** between the first measurement (M = 214.16) and fourth measurement (M = 185.96). In **FEG** in subjects with **higher** level of **Transformation of Time, mean reaction time decreased** between the first measurement (M = 237.36) and second (M = 198.7), third (M = 196.3) and fourth measurement (M = 196.44). In dimension **Autotelic Experience (9)** - a **main effect of measurement** was observed: F(3,21) = 4.888 p = 0.010, η2 =.411. In **FEG** in subjects with **higher** level of **Autotelic Experience** dimension, mean **reaction time decreased** between the first measurement (M = 242.74) and second (M = 204.43), third (M = 196.55) and fourth measurement (M = 201.48).

Reaction Time in VMDD. Results Summary

It is worth noting that in the **VMDD** task in all dimensions in the **Fixed Environment Group (FEG)**, a significant **main effect of measurement** was observed in those with **higher** levels in a particular flow dimension. In the **VEG**, this effect was observed in only two dimensions: **Clear Goals** (3) and **Transformation of Time** (8) and among those with a **lower** score on the **Challenge-Skill Balance** dimension (1). No interaction effect was observed in any of the dimensions.

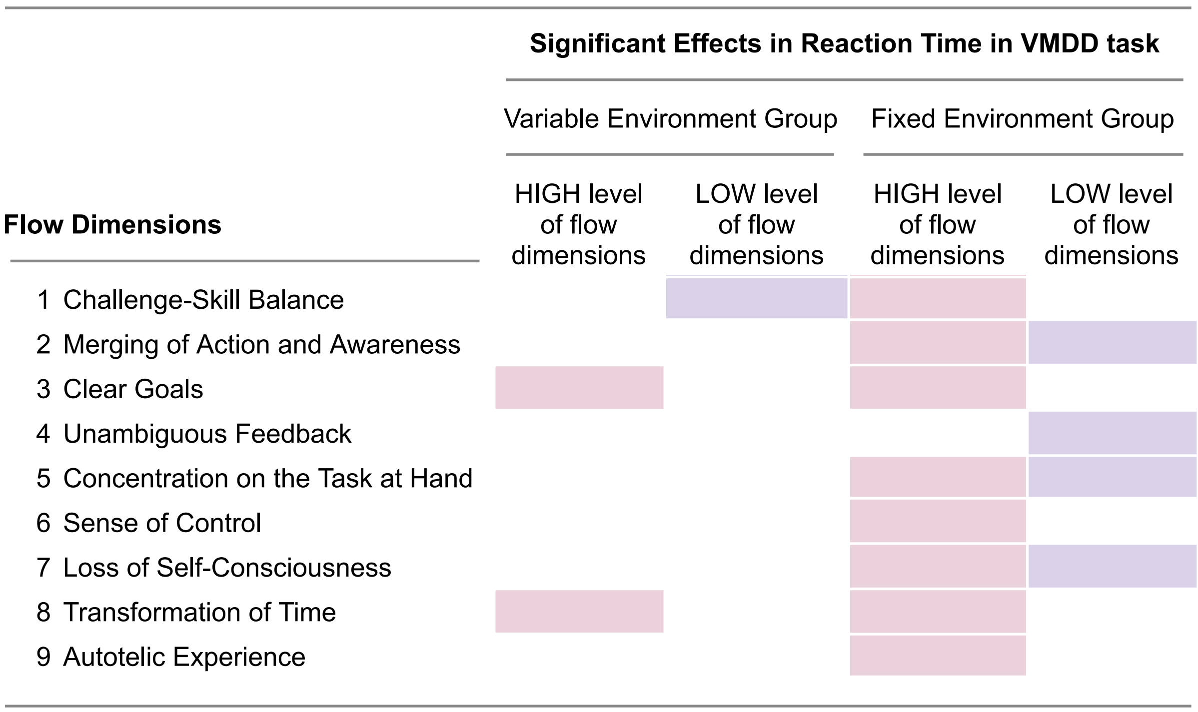


Figure 31. Differences in the significance of measurement effects in response time in the VMDD task for two groups: VEG and FEG for subjects with different levels in the flow dimensions

Accuracy in VMDD

An analogous process using ANOVA analysis was carried out to verify the level of accuracy of responses. In order to test whether the amount of game training - **measurements**, its quality - **groups**, in the group with a higher/ lower **level of every flow dimension** affects the **accuracy** in **visual motion direction discrimination**, ANOVA analyses were conducted for dimension of flow, treating measurement (4) as a within-subject factor, and taking as a between-subject factor: **group** (VEG, FEG) and **dimension of flow level** (high or low).

Table 38. Accuracy (%). Visual Motion Direction Discrimination

dimension	effect	F	df	significance	η2
Mean Flow	measurement	8.676	3, 21	<0.001	.553
Challenge-skill balance (1)	measurement	10.550	3, 21	<0.001	.601
Merging of action and awareness (2)	measurement	8.615	3, 21	<0.001	.552

Clear goals (3)	measurement	8.263	3, 21	<0.001	.541
Unambiguous feedback (4)	measurement	8.933	3, 21	<0.001	.561
Focus on the task at hand (5)	measurement	9.809	3, 21	<0.001	.584
Sense of control (6)	measurement	7.412	3, 21	0.001	.514
Loss of Self-Consciousness (7)	measurement	7.095	3, 21	0.002	.503
Transformation of time (8)	measurement	8.121	3, 21	<0.001	.537
Autotelic experience (9)	measurement	8.307	3, 21	<0.001	.543

The following describes the results of accuracy analyses in the VMDD task, separately for each of the flow dimensions, with attention to accuracy dynamics by VEG and FEG.

In **Challenge-Skill Balance** (1) dimension - a **main effect of measurement**: $F(3, 21) = 10.550$, $p = <.001$, $\eta2 = .601$ and **measurement - Challenge - Skill Balance level interaction tendency** were observed: $F(3, 21) = 2.748$, $p = .068$, $\eta2 = .282$.

In **VEG**, in subjects with **lower** level of **Challenge-Skill Balance dimension, level** of accuracy increased between the first measurement (M = 64.25) and the fourth measurement (M = 67.87). In **FEG** in subjects with **higher Challenge-Skill Balance dimension**, the mean level of response accuracy increased between the first measurement (M = 60.33) and the second (M= 64.93), third (M = 66.96) and fourth measurement (M = 65.18). In subjects with **lower Challenge-Skill Balance dimension** mean level of response accuracy increased between the first measurement (M = 61.53) and the second (M= 68.71), third (M = 72.23) and fourth measurement (M = 73.71), and also between second and fourth measurement.

A similar situation, but without the tendency to interaction, is observed in **Merging of Action and Awareness** (2) dimension - a **main effect of measurement** was observed $F(3, 21) = 8.615$ $p < .001$, $\eta2 = .552$. In **VEG** in subjects with **lower Merging of Action and Awareness** dimension, the mean level of accuracy increased between the first measurement (M = 67.33) and the fourth measurement (M = 71.6). In FEG in subjects with **higher Merging of Action and Awareness dimension** mean level of accuracy increased between the first (M = 66.89) and second (M = 72.5), third (M = 75.95) and fourth measurement (M = 75.76) and also between second and third and fourth measurement. In FEG in subjects with **lower Merging of Action and Awareness dimension**, the mean level of accuracy increased between the first (M = 56.34) and second (M = 61.7), third (M = 63.55) and fourth measurement (M = 62.5).

By analogy in the **Clear Goals** (3) dimension - a **main effect of measurement** was observed $F(3, 21) = 8.263$ $p < 0.001$, $\eta2 = .541$. In **VEG** in subjects with **lower Clear Goals dimension** mean level of accuracy increased between the first measurement (M = 68.75) and the fourth measurement (M = 72.84). In FEG in subjects with **higher Clear Goals dimension** mean level of accuracy increased between the first (M = 60.92) and second (M = 66.71), third (M = 69.02) and fourth measurement (M = 68.8). In FEG in subject with **lower Clear Goals dimension** mean level of accuracy increased between the first (M = 68.75) and second (M = 72.53), third (M = 73.76) and fourth measurement (M = 72.84).

The situation is somewhat different in **Unambiguous Feedback** (4) dimension - a **main effect of measurement** was observed $F(3, 21) = 8.933$ $p < .001$, $\eta2 = .561$. In **VEG** in subjects with **higher** - not lower, like in previous dimensions - **Unambiguous Feedback** mean level of accuracy increased between the first measurement (M = 69.72) and second (M = 74.19), third (M = 76.42) and fourth measurement (M = 74.95). In **FEG** in subjects with **higher Unambiguous Feedback dimension**, the mean level of accuracy increased between the first (M = 58.9) and second (M = 63.45), third (M = 65.5) and fourth measurement (M = 64.85). In **FEG** in subject with **lower Unambiguous Feedback** dimensions, the mean level of accuracy increased between the first (M = 62.05) and second (M = 68.15), third (M = 71.04) and fourth measurement (M = 70.3).

Just like in the first dimension in **Focus on the Task at Hand** (5) dimension - a **main effect of measurement**: $F(3, 21) = 9.809$, $p = <.001$, $\eta2 = .584$ and **measurement - Focus on the Task at Hand interaction tendency** were observed: $F(3,21) = 2.431$, $p = .094$, $\eta2 = .258$.

In **VEG**, in subjects with **lower** level of **Focus on the Task at Hand** dimension, the level of accuracy increased between the first measurement (M = 71.4) and second (M = 76.85), third (M = 79.15) and the fourth measurement (M = 77.64). In **FEG** in subjects with **higher Focus on the Task at Hand** dimension, the mean level of response accuracy increased between the first measurement (M = 64.4) and the second (M= 69.15), third (M = 72.24) and fourth measurement (M = 72.5). In subjects with **lower Focus on the Task at Hand dimension** mean level of response accuracy increased between the first measurement (M = 55.63) and the second (M= 62.06), third (M = 63.8) and fourth measurement (M = 61.8).

In the next dimension, as the only one, the effect was observed only in the FEG. For the **Sense of Control** (6) dimension - a **main effect of measurement** was observed $F(3, 21) = 7.412$ $p = .001$, $\eta2 = .514$. In **FEG** in subjects with **higher Sense of Control dimension** mean level of accuracy increased between the first (M = 61.7) and second (M = 66.46), third

(M = 69.63) and fourth measurement (M = 69.43), and also between second and third and fourth measurement. In FEG in subject with **lower Sense of Control** dimension, mean level of accuracy increased between the first (M = 58.82) and second (M = 65.66), third (M = 66.89) and fourth measurement (M = 65.21).

Then the **Loss of Self-Consciousness** (7) dimension - a **main effect of measurement** was observed $F(3, 21) = 7.095$ $p = .002$, $\eta 2 = .503$. In **VEG** in subjects with **lower Loss of Self-Consciousness** dimension, the mean level of accuracy increased between the first measurement (M = 68.16) and second (M = 71.85), third (M = 72.7) and the fourth measurement (M = 73.0). In **FEG** in subjects with **higher Loss of Self-Consciousness** dimension, the mean level of accuracy increased between the first (M = 63.5) and second (M = 68.9), third (M = 71.5) and fourth measurement (M = 71.55), and also between second and fourth measurement. In FEG in subjects with **lower Loss of Self-Consciousness** dimension, the mean level of accuracy increased between the first (M = 55.3) and second (M = 60.84), third (M = 63.22) and fourth measurement (M = 60.7).

And again a bit different in the **Transformation of Time** (8) dimension - a **main effect of measurement** was observed $F(3, 21) = 8.121$ $p < .001$, $\eta 2 = .537$. In **VEG** in subjects with **higher Transformation of Time** dimension, the mean level of accuracy increased between the first measurement (M = 66.18) and second measurement (M = 69.89). In **FEG** in subjects with **higher Transformation of Time** dimension mean level of accuracy increased between the first (M = 61.5) and second (M = 65.84), third (M = 69.1) and fourth measurement (M = 68.72), and also between second and third and fourth measurement. In FEG in subjects with **lower Transformation of Time** dimension, the mean level of accuracy increased between the first (M = 59.7) and second (M = 66.7), third (M = 68.24) and fourth measurement (M = 67.04).

And finally in the **Autotelic Experience** (9) dimension - a **main effect of measurement** was observed $F(3, 21) = 8.307$ $p < .001$, $\eta 2 = .543$. In **VEG** in subjects with **higher Autotelic Experience** dimension, the mean level of accuracy increased between the first measurement (M = 63.23) and fourth measurement (M = 68.1). In **FEG** in subjects with **higher Autotelic Experience** dimension, the mean level of accuracy increased between the first (M = 63.3) and second (M = 68.9), third (M = 71.11) and fourth measurement (M = 70.83). In FEG subjects with **lower Autotelic Experience** dimension, the mean level of accuracy increased between the first (M = 57.2) and second (M = 62.41), third (M = 65.4) and fourth measurement (M = 64.1).

Accuracy in VMDD. Results Summary

With regard to the level of accuracy in the VMDD task, the **main effect of the measurement** was observed in all dimensions and **only two interactions**, in addition only **at the trend level**: Challenge-Skill Balance (1) and Focus on the Task at Hand (5).

In the **FEG**, the **accuracy of responses increased** statistically significantly **in all dimensions for all participants**, regardless of their level in a particular flow measurement. In VEG, on the other hand, statistically significant increase was observed primarily in the group with lower scores on most dimensions. The exceptions to this were the dimensions of Unambiguous Feedback (4), Transformation of Time (8) and Autotelic Experience (9) dimensions, which showed an increase in the group with **higher levels** in the flow dimension.

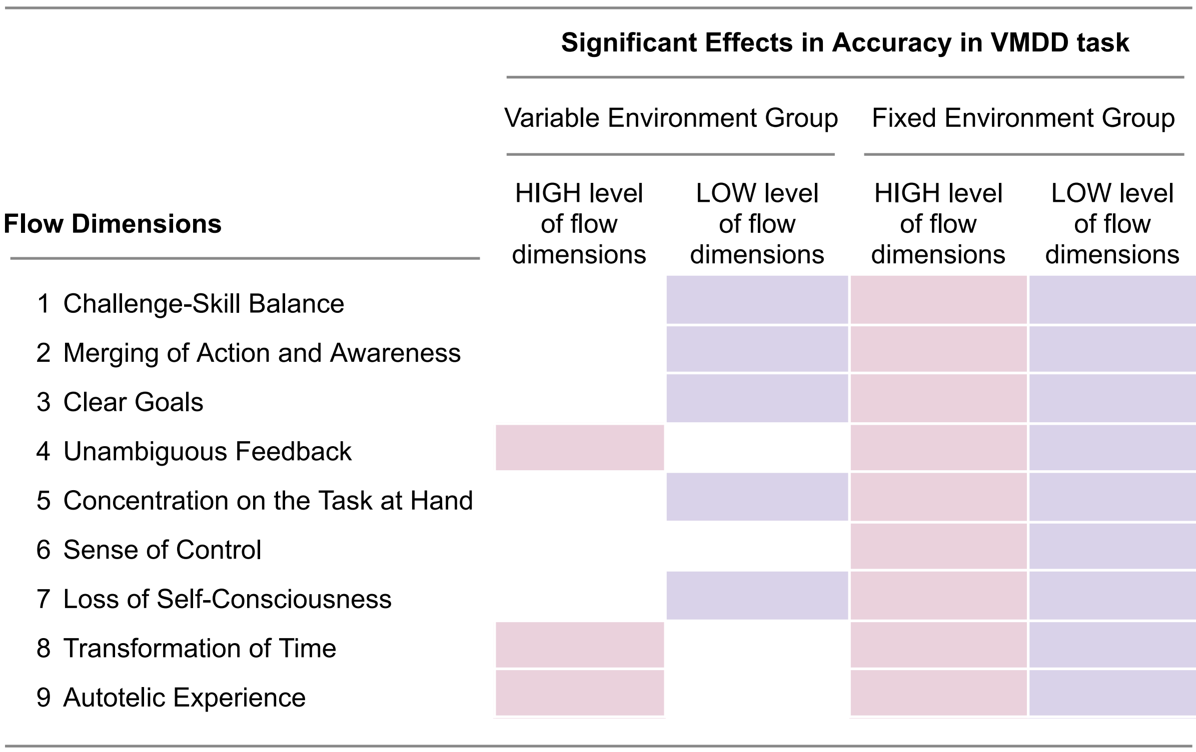


Figure 32. Differences in the significance of measurement effects in accuracy in the VMDD task for two groups: VEG and FEG for subjects with different levels in the flow dimensions

Stop Signal

H.3.4.a The accuracy and signal inhibition response time during the learning process of a complex skill varies depending on the average level of flow that the participant reported during the game measurement. (Stop Signal, PFSS-2)

To test whether the accuracy and response time of signal inhibition during the learning process of a complex skill varies according to the average flow level the participant reported when measured during the game ANOVA analyses were conducted, considering **measurement** (4) as a within-subject factor and **group** (VEG, FEG) and **flow level** (high or low) as a between-subject factor.

In the Stop Signal task, the analysis showed **no significant effects** on the accuracy and response time of signal inhibition depending on the **Mean Flow** rate the participant reported during the game measurement.

H.3.4.b The accuracy and signal inhibition response time during the learning process of a complex skill varies - in each flow dimension - depending on the level the participant recorded in a given dimension when measured during the game. (Stop Signal, PFSS-2)

In the next step, analogous analyses were conducted for the nine dimensions of flow. To test whether the accuracy and response time of signal inhibition during the learning process of a complex skill varies according to the dimension flow level the participant reported when measured during the game ANOVA analyses were conducted, considering **measurement** (4) as a within-subject factor and **group** (VEG, FEG) and **dimension of flow level** (high or low) as a between-subject factor.

In contrast to previous tasks, few significant effects were observed, only in Stop Signal Delay in dimension **Loss of Self-Consciousness (7)** and **tendency** in **Sense of Control (6)**. No significant effects were observed in SSRT.

In sixth dimension - **Sense of Control -** significant **measurement - group interaction tendency** was observed: $F(3, 15) = 2.985$, $p = .065$, $\eta2 = .374$ in VEG in subjects with **lower** level of **Sense of Control** SSD **increased** between second (M = 209.52) and fourth (M = 316.51) measurement. Similarly, the FEG level of **SSD increased** between first (M = 332.55) and second measurement (M = 401.97).

Level of Self-Consciousness (7)

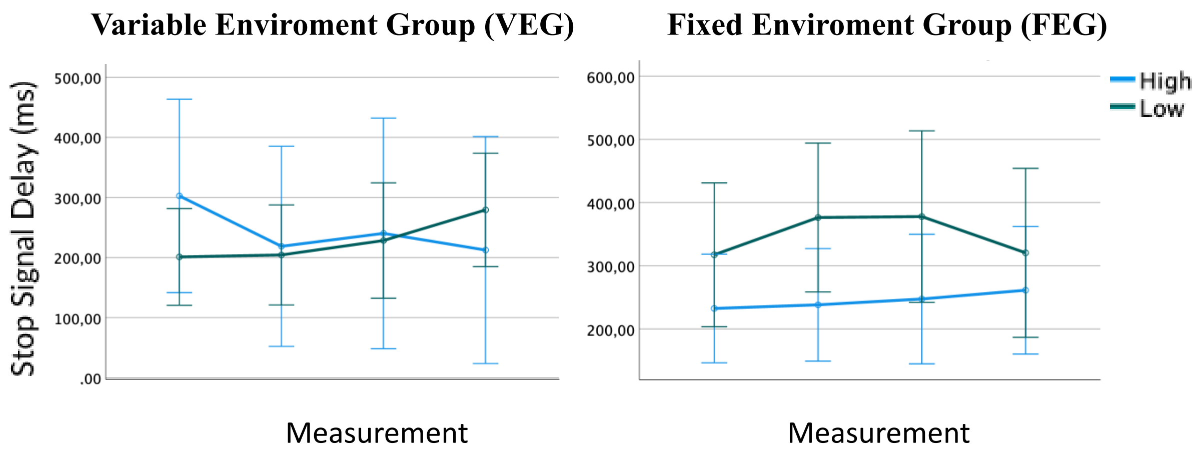


Figure 33. Stop Signal Delay as a function of Loss of Self-Consciousness dimension (High vs. Low), group (FEG vs VEG) and measurement point

Whereas in seventh dimension - **Loss of Self-Consciousness -** significant **measurement - group interaction effect:** $F(3, 15) = 5.898$, $p = .007$, η2 = .541 and **measurement - Loss of Self-Consciousness interaction effect**: $F(3, 15) = 5.602$, $p = .009$, η2 =.528 was observed. In **VEG** in subjects with **higher** levels of **Sense of Control** SSD **decreased** between first (M = 302.74) and second (M = 218.81) measurements. Whereas in **FEG** level of **SSD increased** between first (M = 317.43) and second measurement (M = 376.37).

Those with higher scores on the Loss of Self-Consciousness dimension (7) in the VEG group lowered the amount of time they took to stop the activity. For those with a low score on this dimension, the relationship worsened - rising from measurement to measurement.

In the FEG group of those with a high score on the Loss of Self-Consciousness (7) dimension, the score worsened slightly, and in those with a low score, after worsening in the second measurement, it declined in the fourth measurement returning to the starting point.
No other significant effects were observed.

Summary

The **memory updating** study found that the level of flow, experienced during the training process with an RTS game significantly impacts the memory updating accuracy. The higher the flow state or the scores on specific flow dimensions, the lower the memory accuracy and the greater the memory updating accuracy. This trend was consistent across all nine flow dimensions. The study highlighted the critical role of the sense of control in memory task performance. Those with a lower sense of control experienced a decline in accuracy over time. Importantly, the study demonstrated that flow state and its individual dimensions directly impact memory updating accuracy. This new insight expands our understanding of how flow states can enhance learning and skill acquisition.

In the **task switching** study, flow levels had different effects on switching costs depending on the condition and the group. High flow levels led to decreased switching costs in the global-local condition and among high flow level participants in the Variable Environment Group (VEG). However, high flow individuals initially had higher switching costs than low flow individuals in both conditions. The results also showed the importance of individual flow dimensions in affecting switching costs. In VEG, lower scores in certain dimensions led to decreased switching costs over time, while the Fixed Environment Group (FEG) showed mixed results.

In the **Visual Motion Direction Discrimination** (VMDD) task improved accuracy and faster reaction times in the VMDD task were generally observed among participants with higher mean flow scores. The Variable Environment Group (VEG) with higher mean flow scores demonstrated an increase in accuracy over time. The Fixed Environment Group (FEG) with higher mean flow scores showed improvements in both accuracy and reaction time. Notably, significant improvements in accuracy in the FEG were only observed among participants with lower mean flow scores.

In the study examining the relationship between flow and **reaction inhibition** during the learning process of a complex skill achieving a state of flow as a whole did not seem to optimize the accuracy and response time of signal inhibition. However, specific flow dimensions, particularly Sense of Control and Loss of Self-Consciousness, were found to influence signal inhibition in both variable and fixed environments. Notably, participants in the Variable Environment Group (VEG) with higher levels of these dimensions showed improvement in their Stop Signal Delay (SSD). Conversely, the Fixed Environment Group (FEG) showed an increase in SSD over time.

5.4. Discussion

This dissertation focuses on the importance of flow - as a trait and a state - for learning complex skills. In order to realize the key research it was necessary to prepare a tool for studying flow in the Polish-speaking population. Hence, the first step was a multi-stage validation of the Flow State Scale - 2 and Dispositional Flow Scale - 2 tools. In the next step, a series of studies were implemented as part of a complex sub-longitudinal project, the elements of which are included in the presented work. Due to the limited time, the multiplicity of data and the level of complexity of the analyses, the work presented here refers only to part of the analyses included in the project. The remaining data are still being analyzed, and the results will be published successively.

In response to the recommendations (Kawabata & Mallet, 2016) regarding future research directions, a longitudinal study was conducted, examining participants in repeated measurements (4 - for cognitive function studies, up to 11 measurements for flow and task load, 60 hours for analyzed gameplay) over approximately 3 months. As learning environments, the game Star Craft 2 was used, which, according to Green and Bavelier (2015), represents a group of successful video games that induce high levels of motivation and arousal, provide immediate feedback, offer rewards, and utilize difficulty levels that are appropriately increased based on the player's skills. Each of these features is known to promote time spent on task and enhance effective learning. Participants were divided into two training groups, VEG and FEG, experiencing different levels of complexity in the game environment (3 combinations vs. 15 combinations). This allowed for an examination of the significance of diversified challenges in the learning process.

Green and Bavelier (2015) emphasize that unlimited variety in a game may be counterproductive and slow down learning.

The key part of the work consists of three parts, centered around research questions concerning:

- the relationship of a player's state flow to his performance in real-time strategy games as measured by telemetry variables,
- behavioral and mental predictors that can determine a player's predisposition to achieve higher levels of flow,
- relationships of the flow achieved by a player during training implemented using an RTS game with thetraining-related improvementin cognitive tasks.

1. **Will the level of a player's perceived flow state be related to his performance in real-time strategy (RTS) games as measured by telemetry variables?**

First series of analyses aimed to explore a relationship between match results and perceived flow state. The overall results suggest that such a relationship exists. The first hypothesis posited that perceived flow state is positively correlated with the averaged game performance. Correlational analyses indicated a moderate positive correlation between mean match results and flow state (rho = 0.310, p = <0.001), providing support for this hypothesis. The results suggest that when participants perceived themselves to be in a higher flow state, they were likely to perform better in games.

The second hypothesis assumed that we will see this relationship on the session by session level. Pearson's correlation analysis revealed significant positive relationships between the level of flow in all dimensions and the game performance averaged from the last session before flow measurement. However, the strength of these relationships was generally weak (r < 0.3), suggesting that while flow state is related to better performance in game, it doesn't explain a large portion of the variability in match scores.

The final hypothesis proposed that perceived flow state is positively correlated with the score of the last game before measurement and this was supported by the statistically significant differences in perceived flow states between won and lost matches (with higher flow level in won matches), with the exception of 'Loss of Self-Consciousness' and 'Time transformation' components of flow. This supports the hypothesis that winning games is characterized by higher levels of expierienced flow than losing ones.

To summarize, the research results indicated that there's a relationship between perceived flow state and match results. The perceived flow state was found to be positively related to match performance, as hypothesized. However, the strength of these relationships varied, suggesting that while flow state may contribute to improved gaming performance, other factors, not considered in this research, are also important.

So far, the evidence cited in the literature is not sufficient to unequivocally confirm that flow positively affects performance (Harris, 2021). In a number of sports and gaming tasks, flow has shown a consistent relationship with performance, but there is uncertainty about either how flow affects performance or even the direction of that relationship. The results of our study provide an argument in support of the thesis of a positive relationship between flow and in-game performance, with the low strength of these relationships being difficult to ignore. It's also worth noting that the effect sizes (Cohen's d) were moderate for some aspects of the flow state (e.g., Challenge-Skill Balance, Unambiguous feedback, and

Sense of control), suggesting that these components of flow may be particularly important for gaming performance. However, the effect size was smaller for other aspects of flow (e.g., Loss of Self-Consciousness and Time transformation), indicating that these components may not have as strong of an impact on performance. For future research, it could be interesting to explore these other factors and their interaction with flow state. For instance, player skill level, game type, and player motivation might be worth considering.

Regarding the relationship between playing time and flow hypothesis stating that perceived flow state in a session is positively correlated with the average time of individual games in a session is mostly not supported. The only significant finding is a positive correlation between the sense of control and mean training time in a session, suggesting that a greater sense of control during gameplay could lead to longer gaming sessions. However, this correlation is weak. Contrarily, the negative correlation between mean training time in a session and the merging of action and awareness indicates that players who lose themselves more in the game (a higher degree of merging action and awareness) tend to have shorter sessions.

The hypothesis stating that perceived flow state in a session is positively correlated with the amount of time elapsed since the previous game day is generally not supported. In fact, there is a weak, but statistically significant negative correlation between time since the last session and the autotelic experience, suggesting that longer breaks between sessions may decrease the intrinsic reward players receive from gameplay (autotelic experience).

The hypothesis stating that perceived flow state in a session is positively correlated with the amount of total playtime preceding the measurement on a given day is generally supported. Most flow dimensions had a positive correlation with session time, implying that longer playing sessions are associated with an increased level of flow, but the strength of these relationships was weak. This observation is consistent with previous studies that indicate the importance of the length of the measurement block (Bisson, Tobin & Grondin, 2012; Tobin, Bisson & Grondin, 2010; Yun et al., 2017) setting the minimum at 25 minutes for the participant to have a chance to enter the flow state.

The hypothesis that perceived flow in a session is positively correlated with the amount of time left for the participant to complete the study is not entirely supported. There was only a weak positive correlation between the time left for the participant to complete the study (Time to Training End) and the autotelic experience, implying that knowing they have more time left to complete the study might slightly increase the level of intrinsic rewards players get from gameplay. However, the strength of the correlation is weak.

In conclusion, these results suggest that the **perceived state of flow is not strongly associated with gameplay timing factors** like the average time of individual games in a session, the time elapsed since the last game day, total playtime preceding the measurement, and the time left to complete the study. However, longer sessions tend to be associated with higher levels of flow, and a greater sense of control may lead to longer individual gameplay sessions.

The hypothesis, suggesting that perceived flow state in a session is positively correlated with the difficulty level, is largely supported by the data.

Based on the results from the Spearman's rho correlation analysis, there's a significant positive correlation between the level of gameplay difficulty and the overall flow rating. This indicates that as the difficulty level increases, the flow level assessment also tends to increase. This relationship appears to be especially strong in the case of certain dimensions of the flow state, such as Challenge-Skill Balance (1), Merging of Action and Awareness (2), Clear Goals (3), and Unambiguous feedback (4). These findings suggest that higher game difficulty levels might induce a stronger sense of balance between challenges and skills, a greater merging of actions and awareness, clearer goals, and more unambiguous feedback, thereby enhancing the flow state.

However, for other dimensions like Concentration on the Task at Hand (5), Loss of Self-Consciousness (7), and Transformation of time (8), there was no significant correlation found with the difficulty level. This suggests that the level of difficulty may not influence these specific aspects of the flow state.

Looking at the results from the perspective of two theoretical models of flow state (Csikszentmihalyi, 2000, Stavrou & Zervas, 2004), we see a similar story. There's a moderate positive correlation between the difficulty level and proximal dimensions in the Csikszentmihalyi model ($rho = 0.454, p < 0.001$) and proximal dimensions in the Stavrou and Zervas model ($rho = 0.390, p < 0.001$). This implies that as the difficulty level of the game increases, so does the perceived flow state according to these models. The correlations are weaker, though still significant, with experiential dimensions in the Csikszentmihalyi model ($rho = 0.184, p = 0.004$) and experiential dimensions in the Stavrou and Zervas model ($rho = 0.208, p < 0.001$), suggesting that the experiential aspects of flow as captured by these models also increase with the difficulty level, albeit to a lesser extent.

In conclusion, the difficulty level of the game seems to play a crucial role in enhancing the flow state. It could be a key variable for game designers to manipulate in order to optimize player engagement and satisfaction. However, care should be taken to ensure that difficulty does not increase to a point where it becomes frustrating or demotivating for players. Additionally, the role of difficulty in shaping certain flow dimensions such as concentration, loss of self-consciousness, and time transformation might be less pronounced or non-existent, indicating that other factors may be at play in these dimensions. Further research might explore these complex relationships in greater depth.

The next hypothesis postulated a positive correlation between perceived Flow State and telemetry data such as actions per minute (APM), hotkeys, and PACs Per Minute, and a negative correlation with PACs Action Latency. In line with this hypothesis, our Spearman's rho correlation analysis shows significant positive correlations between the Flow State and several telemetry measures: Hotkeys Total, First Attack Move Time, Total Army Units, and PACs Per Minute. The strongest of these correlations is seen with Hotkeys Total and First Attack Move Time (rho=0.333 and rho=0.336, respectively, both $p<0.001$). This suggests that players who experience a high degree of flow are more likely to use hotkeys, attack earlier, maintain larger armies, and exhibit more frequent perception-action cycles per minute.

There was also a significant negative correlation between Flow State and PACs Action Latency (rho=-0.290, $p<0.001$). This implies that the time delay from the start of the perception-action cycle to the first action taken is shorter for players experiencing high levels of flow, indicating more proficient gameplay. The dimension of Flow most strongly correlated with these telemetry metrics was "Merging of action and awareness (2)", suggesting that high-flow states may be characterized by a strong integration of action and awareness, reflecting in more efficient gameplay.

Next hypothesis investigated relationships between telemetry indicators and two flow models revealed a strong positive correlation between PACs Per Minute and all flow model variables, including model of Csikszentmihalyi Stavrou and Zervas model. This suggests that more frequent perception-action cycles during the last game before flow measurement is associated with higher flow states according to both models.

Last hypothesis suggested that the perceived Flow State is positively correlated with averaged telemetry scores between groups, divided based on their tendency to experience high or low flow. The results confirm this hypothesis, showing a strong positive correlation between PACs Per Minute and Flow State Mean (rho=0.521, p=0.005), and a moderate positive correlation between Average APM and Flow State (rho=0.402, p=0.038).

In summary, the results suggest a strong connection between flow state and in-game proficiency as captured by telemetry data. Players experiencing a higher state of flow demonstrated more actions per minute, efficient use of hotkeys, earlier first attacks, and maintained larger armies, suggesting a higher level of in-game proficiency. These results underline the potential of flow state as a key factor in enhancing gaming performance, with implications for game design and the development of interventions to promote flow in gaming contexts.

In conclusion, the analyses conducted for the first research question: *Will the level of a player's perceived flow state be related to his performance in real-time strategy (RTS) games as measured by telemetry variables?* investigated the relationship between perceived flow state and basic telemetry data during game training. The results indicated a positive correlation between flow state and match performance, suggesting better performance in games when players experience flow state. Some aspects of flow were found to be particularly important for game performance. Game difficulty was key in increasing flow state, and game proficiency correlated strongly with flow state. Players in higher flow state performed more actions per minute, used keyboard shortcuts effectively, made their first attacks earlier and had larger armies, indicating higher proficiency. Factors related to gameplay time were not strongly related to flow state, but longer sessions showed higher levels of flow. In discussing (Kawabata & Mallet, 2016) whether experiencing flow is associated with improved performance, the study's results support the thesis of a positive relationship.

2. Are there behavioral and mental predictors that can identify a player's predisposition to achieve a higher level of flow?

The second aim of the thesis centered on **identifying potential mental predictors that could anticipate a player's likelihood to reach higher levels of flow**. Delving into: dispositional flow, personality traits and intelligence level. Furthermore, recurring metrics collected during the Star Craft II training - encompassing aspects like sense of task load during learning, and perceived flow state - served as key indicators in the ongoing analysis of the learning process.

The first part of the study verified the relationship between a player's **predisposition to flow and their experience of flow while learning complex game skills was examined**. The comparison of Flow and Dispositional Flow scales revealed significant differences in measures of Challenge-Skill Balance, Concentration on the Task at Hand, Loss of Self-Consciousness, and Autotelic Experience. A strong positive correlation was found between a player's predisposition to flow and the experience of flow states during gaming. However, the dimension of Loss of Self-Consciousness showed a weak correlation, indicating this aspect of flow might not be as prominent during complex skill learning. This part emphasizes the influence of certain traits on the learning process within a gaming context.

The next analysis investigated the **correlation between the five major personality traits** (Neuroticism, Extraversion, Openness, Agreeableness, and Consciousness) and the **flow experienced by game players**. The central findings of the study show significant correlation between certain personality traits and dimensions of flow. Using multivariable regression analysis the study identified significant links, particularly focusing on the personality trait of Neuroticism and its relationship to the flow state.

The trait of Neuroticism consistently showed a negative correlation across different dimensions of flow. It negatively impacted the Mean Flow ($\beta = -0.629$, $p = 0.006$), as well as dimensions like Challenge-Skill Balance, Clear Goals, Unambiguous Feedback, and Sense of Control. This suggests that individuals with high levels of Neuroticism may find it harder to attain a flow state, likely due to tendencies towards worry, anxiety, and emotional instability that come with high Neuroticism. These findings confirm previous studies according to which neuroticism negatively correlates with flow experiences, indicating that people with high neuroticism may have difficulty achieving a state of flow due to a tendency toward anxiety and self-doubt (Csikszentmihalyi, 1997; Jackson and Marsh, 1996). The ability to maintain a balance between challenge and skill, a key aspect of flow, is negatively affected by neuroticism, suggesting that individuals with high neuroticism may have difficulty achieving an optimal balance between challenge and skill in their activities (Csikszentmihalyi, 1997; Jackson and Eklund, 2002). The sense of control during flow experiences is negatively affected by neuroticism, suggesting that individuals with high neuroticism may perceive lower levels of control over their actions and outcomes during the flow state (Jackson and Eklund, 2002; Swann, Chiroro and Haddock, 2004).

Interestingly, the traits of Extraversion, Openness, Agreeableness, and Consciousness did not show significant correlation with the Mean Flow. This is consistent with previous reports, where extraversion, openness, agreeableness and conscientiousness did not show consistent or significant relationships with various dimensions of flow, suggesting that these personality traits may not be strong predictors of flow experiences (Fullagar, Knight, & Sovern, 2013; Harari et al., 2016). However, Openness did show a positive correlation with the dimension of Transformation of Time, indicating that individuals with higher Openness might be more likely to lose track of time while in a flow state, which confirms the observations of Harari et al. (2016) and Jackson and Eklund (2002).

On the other hand, the Extraversion, Agreeableness, and Consciousness showed no substantial effect on most dimensions of flow. These traits did not significantly contribute to predicting the Mean Flow, suggesting that they might not play a crucial role in influencing the attainment of a flow state.

In conclusion, based on the multivariable regression analysis, there is a relationship between the personality trait of Neuroticism and the experience of flow. High Neuroticism may hinder the achievement of flow, potentially impacting a player's overall gaming experience. The personality trait of Openness also shows some connection, specifically to the flow dimension of Transformation of Time, while the traits of Extraversion, Agreeableness, and Consciousness showed minimal impact on flow in this study.

It was also verified **whether personality traits affect effectiveness in the game, and whether the perceved level of flow important in this relationship**. As Neuroticism significantly predicted several dimensions of flow it seemed interesting to check whether expierienced flow could explained the impact of Neuroticism on game performance. Series of mediation analyses with Mean Flow, Challenge-Skill Balance, Clear Goals, Unambiguous Feedback, and Sense of Control as mediators confirmed that the relationship between Neuroticism and game performance measured with Perception Action Cycle (PAC) is explanable by flow variables. Similar, but less pronounced, was relationship betwenn game performance, flow and Agreeableness. The latter significantly predicted PACs per Minute, and this relationship was a mediated by averaged flow level. .

In conclusion, Neuroticism seems to affect a player's performance (PACs per Minute) in the game, and this relationship is mediated by several dimensions of flow, such as Mean

Flow, Challenge-Skill Balance, Clear Goals, Unambiguous Feedback, and Sense of Control. On the other hand, Agreeableness also affects a player's performance, but its relationship with Mean Flow is less clear. While Agreeableness doesn't significantly predict Mean Flow, Mean Flow still plays a significant mediating role in the relationship between Agreeableness and PACs per Minute.

In general, personality traits, specifically Neuroticism and Agreeableness, can influence game performance. Flow and its dimensions appear to be a critical mediators in these relationships, suggesting that understanding and enhancing flow could improve performance, irrespective of personality traits. However, these findings are based on a small sample size, and future research with a larger sample size is required to confirm these observations.

Another analysis focused on examining the **relationship between flow status and intelligence level**. Initially, a Spearman correlation analysis was performed, taking into account all participants, to assess the association between their intelligence level and average perceived flow state. The results showed no correlation, with a correlation coefficient of -0.007 and a p-value of 0.969. These results suggest that, within this sample, there wasn't a direct relationship between the perceived flow state and the level of intelligence.Further, the analysis proceeded by splitting the participants into two groups based on their intelligence scores (lower and higher) intelligence scores. In both groups there was no significant correlation.Finally, the researchers considered the intelligence test scores in relation to age, but this too yielded similar non-significant results.

To summarize, this analysis suggested that within this particular sample of participants, there is no significant relationship between the perceived state of flow and a person's level of intelligence, neither in the full group nor when considering subgroups based on intelligence levels or age. The perceived state of flow appears to be independent of these factors, at least within the context of this study, which confirms the observations of Ullén et al. (2011).

The final element of analysis under research objective No. 2 is to verify the **impact of task load on player flow**. The multivariate regression analysis indicates a significant negative correlation between flow and sense of task load during the learning process, which supports the research hypothesis (H.2.4.a). The model showed that the flow experience (Mean Flow) significantly correlated with Effort and Frustration aspects of the NASA Task Load Index. The increased effort corresponded with higher Mean Flow, while higher frustration led to decreased Mean Flow.

Moreover, when examining individual flow dimensions, the Effort and Frustration components again emerged as significant predictors for several dimensions of flow. Effort showed a positive correlation, implying that an increase in effort enhances flow, while Frustration demonstrated a negative correlation, meaning that higher frustration inhibits flow. Other task load factors (Mental, Physical, Temporal, Performance) showed more complex or negligible relationships with flow.

Further analysis divided games into groups depending on the match outcome (won or lost). Here, the findings again emphasized the role of Frustration and Performance. Both had a negative correlation with Mean Flow for both groups, meaning an increase in these aspects led to a decrease in Mean Flow. However, these correlations were stronger in the group that lost their matches. Interestingly, the negative correlation with performance may suggest a state of optimal performance associated with higher flow, not necessarily low performance. These results seem consistent with the thesis of Peifer et al. (2014), which argues that when physiological stress is elevated, it shows an inverse relationship with flow. The higher the reported level of frustration, the lower the reported level of flow in the subject. The results of the positive relationship between flow and effort seem interesting. They are worth looking at in the context of the results of the analyses in response to the last research question.

Summing up, behavioral and mental predictors predicting higher levels of flow in players were examined. The analysis showed a negative correlation between flow and task load, with effort affecting flow positively and frustration negatively. Other load factors had complex or insignificant relationships with flow. A game-by-game analysis took into account the outcome of the match and confirmed the negative correlation between flow and frustration and performance. The results suggest that higher frustration inhibits flow, while higher performance may be associated with higher flow.

3. **Will the level of flow a player achieves during training with an RTS game be related to the change in cognitive tasks after training?**

The third research question looked at the relationship between flow and four cognitive processes and functions: updating memory, task switching, visual motion direction discrimination and signal inhibition.

Updating memory refers to the ability to modify or revise existing information in memory. It involves adding new information, removing outdated information, or modifying the existing information to reflect the latest knowledge or experiences. **Task switching** is the cognitive process of shifting attention and mental resources from one task or activity to another. It involves disengaging from the current task, selecting a new task to focus on, and then engaging with the new task. Task switching requires cognitive flexibility and the ability to adapt to changing demands. **Visual motion direction discrimination** refers to the ability to perceive and distinguish the direction of moving objects or patterns in the visual field. It involves the processing of visual information related to motion and the brain's ability to analyze and interpret the direction in which an object or pattern is moving. **Signal inhibition** refers to the ability to suppress or inhibit certain responses or behaviors. It involves inhibiting or suppressing automatic or prepotent responses in order to allow for more appropriate or desired responses. Signal inhibition is crucial for self-control, impulse control, and cognitive flexibility.

The analysis focused on examining the influence of flow levels and dimensions on memory updating accuracy during the learning process of a complex skill. The researchers conducted ANOVA analyses, considering various factors such as measurements, group (VEG, FEG), and flow levels (high or low). The results showed that the main effect of measurement was significant, indicating a noticeable improvement in accuracy from the first measurement to the fourth measurement. This suggests that participants were able to enhance their memory updating skills as they progressed through the learning process. Furthermore, the participants' reported average flow levels during the game had an impact on their accuracy. Those with lower flow levels demonstrated lower accuracy, particularly in the early measurements. On the other hand, higher flow levels were associated with better accuracy. The analysis also explored the influence of specific flow dimensions on memory updating accuracy. Several dimensions, including Challenge-Skill Balance, Merging of Action and Awareness, Clear Goals, Unambiguous Feedback, Focus on the Task at Hand, Sense of Control, Loss of Self-Consciousness, Time Transformation, and Autotelic Experience, were found to significantly affect accuracy. In the Variable Environment Group (VEG), participants with higher levels in certain flow dimensions generally exhibited higher accuracy. In contrast, in the Fixed Environment Group (FEG), lower levels in certain flow dimensions were associated with lower accuracy. This suggests that the impact of flow dimensions on accuracy can vary depending on the overall context and environment. Of particular interest was the role of Sense of Control in the change in accuracy during training. Subjects who reported lower levels of Sense of Control and underwent less complex training experienced a decline in accuracy by the third measurement. This finding highlights the importance of perceived control in cognitive performance and suggests that individuals who feel less in control may struggle to improve their memory updating abilities. Overall, the results emphasize the influence of flow experiences on memory updating accuracy during skill acquisition. Higher flow levels and higher levels in specific flow dimensions are associated with improved accuracy. These findings underscore the significance of creating optimal flow experiences to enhance cognitive performance in complex tasks.

Previous studies in this area have been inconclusive - on one hand, Boot et al. (2008) found no improvement in memory accuracy in both players and non-players, while on the other hand, Colzato et al. (2013) indicated improvement in the player group. Given that the participants in our study are non-players who only encountered video games during the project or had very little experience with them, our observations shed new light on the results of previous research. If, according to Colzato et al. (2013), action video game players respond faster and more accurately than non-players in the n-back paradigm, indicating optimized functionality of updating, and in our study, we only examined non-players who improved their results depending on the level of flow, it seems worthwhile to: a. conduct a similar study on a group of players, b. verify, with a larger sample size, to what extent flow mediates the effects.

The findings align with the existing research linking flow state with enhanced learning and skill acquisition. Increased flow levels lead to greater memory updating accuracy, consistent with research showing that higher flow states are conducive to better performance and learning outcomes (Engeser & Rheinberg, 2008).

The findings extend the current knowledge on the role of the sense of control in learning and cognitive performance. Individuals with a lower sense of control had difficulties improving their cognitive functions with training, underscoring the importance of perceived control for efficient learning. This is in line with Bandura's Self-Efficacy Theory (1997), which suggests that one's belief in their ability to succeed (Sense of Control) influences how they think, behave, and feel. This study's results echo earlier research showing that flow experiences enhance task performance (Nakamura & Csikszentmihalyi, 2009). Participants with higher flow levels displayed greater memory updating accuracy, further substantiating the positive correlation between flow states and task performance.

In **Task Switching**, the relationship between switching and flow differed depending on the condition (global vs. local). In the global-local condition, participants with higher mean flow levels were able to significantly decrease their switching costs between the first and fourth measurements. However, in the local-global condition, the effect of mean flow level on switching costs was not significant. In the local-global condition, there was a significant interaction effect between measurement and flow level, but only in the Variable Environment Group (VEG). Participants in VEG with higher flow levels showed a significant decrease in switching costs between the first and fourth measurements, while those with lower flow levels showed a smaller improvement.

Notably, in both the global-local and local-global conditions, participants with higher flow levels initially had higher switching costs compared to those with lower flow levels.

In **global - local condition** different flow dimensions, such as Challenge-Skill Balance, Merging of Action and Awareness, Clear Goals, Unambiguous Feedback, Focus on the Task at Hand, Sense of Control, Loss of Self-Consciousness, Transformation of Time, and Autotelic Experience, showed significant effects on the cost of switching.

The VEG group displayed improvements in switching costs for certain dimensions. Participants with lower levels of Challenge-Skill Balance, Merging of Action and Awareness, Clear Goals, Unambiguous Feedback, Focus on the Task at Hand, Sense of Control, Loss of Self-Consciousness, and Autotelic Experience showed decreased switching costs between the first and fourth measurements. The FEG group exhibited varying results. Participants with lower levels of Merging of Action and Awareness, Sense of Control, and Autotelic Experience experienced increased switching costs between certain measurements.

The mean level of flow dimensions also played a role. Participants with a high average level in Unambiguous Feedback initially increased their switching costs but subsequently decreased them from the second to the fourth measurement. Participants with a low average level in Unambiguous Feedback significantly improved their switching costs, particularly between the first and second measurements.

The dynamics of switching costs differed between the VEG and FEG groups. In the VEG group, those with higher scores on dimensions like Sense of Control and Autotelic Experience showed consistent improvements in switching costs. In contrast, the FEG group experienced deteriorating switching costs, especially for individuals with lower scores in dimensions like Sense of Control and Autotelic Experience.

The analysis of the **local-global condition** in the Merging of Action and Awareness dimension (2), there was a significant interaction effect between measurement and group.

Participants in the Variable Environment Group (VEG) with higher levels in this dimension exhibited a decrease in switching costs over time, while those in the Fixed Environment Group (FEG) with lower levels experienced an increase in switching costs. In the Focus on the Task at Hand dimension (5), a significant interaction effect between measurement and group was observed. Participants in VEG with higher levels in this dimension showed a reduction in switching costs over time, whereas those in FEG with lower levels experienced an increase in switching costs. Similarly, in the Sense of Control (6), a significant interaction effect between measurement and group was found. Participants in VEG with higher levels in this dimension demonstrated a decrease in switching costs, while those in FEG with lower levels displayed an increase in switching costs. In the Loss of Self-Consciousness (7), there was a significant interaction effect between measurement and group. Participants in VEG with higher levels in this dimension showed a decrease in switching costs, while those in FEG with lower levels exhibited an increase in switching costs. Likewise, in the Transformation of Time (8), a significant interaction effect between measurement and group was observed. Both VEG and FEG participants with lower levels in this dimension experienced an increase in switching costs. Lastly, in the Autotelic Experience (9), a significant interaction effect between measurement and group was found. Participants in both VEG and FEG with lower levels in this dimension showed a decrease in switching costs.

In light of previous inconclusive studies (Berryhill and Hughes 2009, Karbach and Kray 2009, Strobach et al. 2012, Wendt et al. 2017), experienced action game players have been found to exhibit lower switching costs compared to non-gamers (Colzato et al., 2010), or no such relationships were observed (Boot et al., 2008, Oei and Patterson 2014, Strobach and Schubert 2021). Due to the fact that our study only involved non-gamers, the results cannot be directly compared with these findings. Participants, initially non-gamers, showed improvements in switching costs with 60 hours of game experience. However, due to the difficulties in defining the transition from non-gamers to gamers, there is currently no clear rationale for changing the classification from non-gamers to gamers. Hard telemetry indicators from the game (playtime, APM, hotkeys, PACs, etc.) could be used, but they do not provide insights into a person's relationship with the game. Does a person who plays for monetary rewards qualify as a gamer? Is there a need for factors such as engagement and enjoyment, which are aspects leading to flow? These are questions that are worth examining from a broader perspective, which is not made easier by the significant diversity of research on games (see 3.3).

An interesting observation is how the dynamics of switching costs differed between the VEG and FEG groups. In the VEG group, individuals with higher scores in dimensions such as sense of control and autotelic experience showed consistent improvement in switching costs. This may indicate that these individuals felt a sense of control over the task, which motivated them to engage in further actions. Meanwhile, the FEG group experienced worsening switching costs among individuals who scored lower in dimensions such as sense of control and autotelic experience. This can be interpreted in relation to the studies by Zajonc and Baron. In a task that is not inherently attractive (high repeatability) and, after acquiring basic skills, requires low competence, attention may focus on survival. The only motivator remaining in this case is external motivation (resulting from an agreement). This is in line with the basic flow indicator (Kawabata & Mallett, 2011, Nakamura & Csikszentmihalyi, 2002) - the balance between skills and challenges. If it is too low, frustration arises.

Overall, these findings highlight that the dynamics of attentional switching costs during the learning process of complex skills in the local-global condition are influenced by the level of perceived flow across various dimensions. Higher levels of engagement-related dimensions, such as Merging of action and awareness, Focus on the Task at Hand, and Sense of Control, were associated with decreased switching costs. Conversely, lower levels in self-awareness-related dimensions, such as Loss of Self-Consciousness and Autotelic Experience, were also linked to decreased switching costs. It is noteworthy that participants in the Fixed Environment Group generally exhibited higher switching costs compared to those in the Variable Environment Group.

These results are important, among others, for dealing with the consequences of civilization development and, consequently, access to knowledge or tools that facilitate access to it (e.g., GPT), where the fundamental skill becomes the ability to learn. Green and Bavelier (2015) point to the adequacy of games for such a learning paradigm. The significant features of games determining this learning effect include diversity (of stimuli, actions, inferences, and others) and the need for flexible use of attention (both in switching between different features when they become relevant to the task and between different states of attention).

The next investigated was the **relationship between the level of flow** achieved during training using a real-time strategy game and the results obtained in the **Visual Motion Direction Discrimination (VMDD)** task. The study aimed to examine whether the mean level of flow and flow dimensions would be related to accuracy and reaction time in the

VMDD task.Regarding accuracy in the VMDD task, the analysis revealed a significant main effect of measurement in all flow dimensions. Participants generally demonstrated improved accuracy from one measurement to another, with higher coherence levels leading to better discrimination performance. However, there was no significant interaction effect between group and coherence level.

When considering the mean level of flow, a significant main effect of measurement was observed, indicating that the level of accuracy varied across measurements. In the Variable Environment Group (VEG), participants with higher mean flow scores showed an increase in accuracy over time. In the Fixed Environment Group (FEG), participants with higher mean flow scores exhibited an increase in accuracy between the first and second measurements, as well as between subsequent measurements. Notably, among participants with lower mean flow scores, statistically significant improvement in accuracy was only observed in the FEG.

Moving on to reaction time in the VMDD task, a significant main effect of measurement was found in all flow dimensions. The analysis indicated that reaction times decreased from one measurement to another, suggesting improved performance. This effect was particularly evident in participants with higher mean flow scores. However, no significant interaction effects were observed in any of the flow dimensions.

In summary, the findings suggest that the level of flow and its dimensions are related to accuracy and reaction time in the VMDD task. Higher mean flow scores were generally associated with increased accuracy and faster reaction times across measurements. This relationship was more pronounced in the FEG, where participants with higher mean flow scores showed significant improvements in both accuracy and reaction time. In the VEG, statistically significant improvements in accuracy were observed primarily among participants with lower mean flow scores.

The results of previous studies in the field of visual motion direction discrimination among gamers are inconclusive. Green et al. (2010) indicated some differences in reaction times compared to non-AVG players, while other studies did not confirm these findings (Hutchinson & Stocks, 2013; Pavan et al., 2016). In the context of our study, I have not found any papers that specifically address the potential influence of flow in this area. Although the existing research has been extensive (Green, Pouget, & Bavelier, 2010; Hutchinson & Stocks, 2013; Pavan, Boyce, & Ghin, 2016; Overney, Blanke, & Herzog, 2008; Kong et al., 2012), it does not address aspects related to flow.

The last section examines the relationship between **flow state** and **reaction inhibition**. Our findings offer some intriguing insights into the relationships between flow dimensions, reaction inhibition, and the learning process of a complex skill within variable and fixed environments. The main conclusions that we could draw from our study are:

Flow as a whole doesn't seem to affect the accuracy and response time of reaction inhibition during the learning process of a complex skill. This suggests that simply achieving a state of flow might not be enough to optimize these particular aspects of learning and performance, contradicting our initial hypothesis. This conclusion is also inconsistent with relevant previous observations (Dobrowolski et al., 2020), which suggest that playing results in a deterioration of response inhibition.

However, specific dimensions of flow – Sense of Control and Loss of Self-Consciousness – appear to play a role in reaction inhibition within variable and fixed environments. In particular, the Variable Environment Group (VEG) participants with a higher sense of control or loss of self-consciousness showed an improvement in their Stop Signal Delay (SSD). Interestingly, the Fixed Environment Group (FEG) showed an increase in SSD between measurements, indicating potential differences in how these environments might affect the role of flow in learning and performance.

Summing up, the analyses conducted for the first research question: *Will the level of flow a player achieves during training implemented using an RTS game be related to the results obtained in a cognitive task?*

Higher levels of flow and scores in flow dimensions are associated with improved accuracy in memory updating tasks. The complexity of training is inversely related to memory load. Sense of control is a crucial factor in memory task performance, with lower control leading to declined accuracy over time.

The relationship between switching and flow differs based on the condition (global vs. local). **Higher mean flow levels are associated with decreased switching costs in the global-local condition.** Specific flow dimensions, such as Challenge-Skill Balance, Merging of Action and Awareness, Clear Goals, Unambiguous Feedback, Focus on the Task at Hand, Sense of Control, Loss of Self-Consciousness, Transformation of Time, and Autotelic Experience, show significant effects on switching costs. The dynamics of switching costs differ between the Variable Environment Group (VEG) and Fixed Environment Group (FEG).

The level of flow and its dimensions are related to accuracy and reaction time in the VMDD task. Higher mean flow scores are generally associated with increased accuracy and faster reaction times. Improvement in accuracy is observed over time, especially in participants with higher mean flow scores.

Flow does not significantly affect the accuracy and response time of signal inhibition during the learning process. However, specific flow dimensions, such as Sense of Control and Loss of Self-Consciousness, play a role in signal inhibition within variable and fixed environments. VEG participants with a higher sense of control or loss of self-consciousness show an improvement in Stop Signal Delay (SSD), while FEG participants show an increase in SSD between measurements.

Overall, the level of flow and its dimensions have varying relationships with different cognitive functions. Flow is positively associated with memory updating accuracy and task switching improvements, while it relates to accuracy and reaction time in the VMDD task. However, flow does not significantly impact reaction inhibition. The specific dimensions of flow, particularly Sense of Control and Loss of Self-Consciousness, show consistent effects across cognitive functions.

At the end, the benefits of action video gaming seem to extend beyond the boundaries of games themselves. This is perhaps fostered by the high entry thresholds in games i.e. Star Craft 2, where the presence of critical links between the variety of stimuli, actions, and inferences can prevent automation and thus increase specificity (Fulvio et al., 2014), as well as structural regularities in the game that ensure that there is always something to learn and that what can be learned is independent of the task (Tenenbaum et al., 2011, Kemp et al., 2010).

Star Craft 2 requires an increased adaptive ability to shift attention in two directions (Green & Bavelier, 2015): a) depending on different task features when they become relevant to the goal, and b) between focused attention (e.g., engaging in combat with an opponent) and distributed attention (e.g., scanning maps and gathering information). By demanding players to flexibly utilize attention at different levels of resolution, games can indeed teach metacognitive control of attention.

On the other hand, ambitious assumptions can come crashing down on methodological difficulties. Khoshnoud et al. (2020) point out significant discrepancies in measurement methods and tools (most commonly FSS-2) as well as varied decisions by researchers regarding measuring global flow or its specific dimensions. Other researchers emphasize the importance of measurement block length (Bisson, Tobin & Grondin, 2012; Tobin, Bisson & Grondin, 2010; Yun et al., 2017), setting a minimum of 25 minutes for participants to have a chance to enter a flow state. The choice of game is an ongoing issue raised by researchers. Games differ dramatically in their demands (e.g., Counter Strike vs. SC2 vs. Tetris), making it inadequate to compare research results from different games in such a sensitive and little-known area as flow.

In our study at the level of statistical analysis, an approach that has not been used before was applied - examining the relationships between flow and cognitive functions, as well as between flow and telemetry data, divided into groups of individuals with higher and lower flow state measurements. This requires sterile testing conditions. Meanwhile, the laboratory conditions of flow research can have a significant impact on its results. I'm not talking about specific conditions, i.e. pandemic, lockdown, or war. Therefore, it is worthwhile to not only examine the task-flow relationship but also the task-context-flow relationship. Referring to the suggestions of researchers who have investigated the relationship between flow and salivary cortisol (Keller et al., 2011; Peifer et al., 2015; Peifer et al., 2014), this association is moderated by the type of intervention, personal characteristics, and the interaction of both factors (Brom et al., 2014). Hence, it is crucial to consider the laboratory setting in the context of a commitment undertaken for compensation.

In light of the study we conducted, despite the difficult conditions and ultimately quite small group in the longitudinal study, the results indicate that the role of player's flow in the complex skill learning is an element worth considering. This is because it is a measurable, tangible indicator that, on the one hand, can be predicted (see: flow vs. predisposition to flow, personality, or task load), and on the other hand, not only can it be directly related to performance on tasks (see: higher flow menad higher proficiency) but also acts as a catalyst (Agreeableness) or as a brake (Neuroticism) on how a person manages his attention in the game (e.g., PACs oper Minute). In addition, the study found numerous correlations between flow or specific flow dimensions and performance on a cognitive task measuring the quality of learning during game training. The results are so promising that the study's authors are preparing further publications in this area. However, it is not only the results that are interesting, but also the unique approach used, e.g. detailed verification of individual flow dimensions, consideration of high and low flow groups, differentiated game environments.

Thus, in the search for the Holy Grail of effectiveness, we see that the direction of exploration is good. More research is needed to look at the phenomenon under more favorable conditions. It's worth it, because peace of mind is at stake. At least some form of it.

5.5. Conclusions

5.5.1. Essential Conclusions

5.5.1.a. Future research directions

Future research directions for researchers may include:

1. The study of flow and its effects on cognitive tasks can be extended to different domains and contexts, such as sports, art, music or work. Studying flow in these different areas can provide insight into how the experience of flow affects performance and satisfaction in different spheres of life.
2. Investigating the neurobiological underpinnings of flow can be an interesting line of research. It is possible to study how the experience of flow is related to brain activity, neurotransmitter levels or the synchronization of different brain areas. Such research can provide a more detailed understanding of the mechanisms of flow.
3. Research can be directed toward the development of flow-based therapeutic interventions. It is possible to study how inducing flow states can affect mental health, reduce stress or improve well-being. Flow-based therapy research can be applied to a variety of fields, such as psychological therapy, rehabilitation or mental health improvement.
4. Investigating how different personality traits, motivations or life experiences affect the experience of flow can provide insight into individual determinants of this condition. It is possible to explore why some people are more susceptible to flow than others, as well as how different factors can affect the quality and intensity of flow experience.
5. Investigating the use of technology, such as virtual reality, computer games or interactive tools, to induce flow states can be an interesting direction. It can be explored how different technologies can be designed and adapted to support the flow experience and improve performance in different tasks.
6. Studying cultural differences in the experience of flow can provide insight into how cultural factors such as values, norms or social expectations affect the occurrence and quality of flow. It is possible to study whether there are cross-cultural differences in flow preferences and experience, and how cultural factors shape this experience.

In summary, future research directions for researchers may include expanding the context, exploring the neurobiological underpinnings, developing therapeutic interventions, analyzing individual differences, applying technology, and studying the cultural determinants of flow. Research in these areas can further our understanding of flow and its role in various aspects of human life.

5.5.1.b.Implications

1. Based on the results of this research work, several potential research directions and implications can be identified:
2. The results suggest that promoting higher flow states during training can potentially reduce memory load and improve cognitive performance. Future research may focus on developing intervention strategies or training programs that specifically aim to improve flow experiences to optimize learning outcomes and cognitive functioning.
3. Further development of reliable and valid tools to assess flow states in the context of cognitive tasks and training could be valuable. This would enable researchers and practitioners to accurately measure and track flow experiences, facilitating the evaluation of interventions and training programs aimed at improving flow and cognitive performance.
4. Studying individual differences in susceptibility to flow and its impact on cognitive tasks could provide valuable insights. Examining factors such as personality traits, motivation and prior experience with games can help identify individuals who are more likely to benefit from flow-related interventions and training approaches.
5. Investigating whether positive effects experienced during training with an RTS game generalize to other cognitive tasks and real-world situations can be valuable. Understanding the transferability of positive flow effects to improve cognitive functioning can inform the design of training programs that effectively improve cognitive functioning across domains.
6. The results have implications beyond the realm of games and cognitive training. The application of flow principles to other learning contexts, such as education, professional development, and skill acquisition in a variety of domains, can potentially improve learning outcomes and performance on tasks. Exploring the application of flow in these diverse contexts can contribute to the development of more effective learning and training methodologies.

7. Investigating the long-term effects of flow experiences on cognitive performance and skill retention is an important area for further research. Understanding whether the benefits of flow persist over time and whether they contribute to long-term cognitive development may provide clues to the sustainability and long-term implications of flow-enhancing interventions.

In conclusion, the results of this research work open up various avenues for further research, including intervention strategies, individual differences and practical applications. Continued research in these areas may contribute to the development of evidence-based approaches that optimize learning, cognitive performance and skill acquisition.

5.5.2. Organizational and Logistical Conclusions

Based on the unique challenges encountered during this research project, implemented amidst the COVID-19 pandemic and the war in Ukraine, we provide the following recommendations:

The design of the longitudinal study should include an element of **piloting, for which the researchers have adequate time, logistical and financial capacity**. This would allow distractors to be eliminated before the team moves on to the main study. This involves, among other things, considering the pilot study with its own budget as an integral part of the project in grant proposals.

To mitigate **communication risks**:

- **Hold Regular Team Meetings.** Maintain a consistent schedule of systematic meetings within the project team. This will facilitate smooth communication, foster team cohesion, and ensure everyone stays updated on project developments.
- **Promote Transparency.** Encourage team members to keep others informed about any difficulties or obstacles they encounter. An environment where concerns can be openly shared and addressed can help preempt major issues.
- **Risk Analysis and Monitoring.** Implement a strategy for risk analysis at the planning stage of projects and ensure ongoing monitoring. Have a set of preventive actions in place, and be prepared to react swiftly when threats materialize.

To address the risk of **team member rotation and knowledge flow**:

- **Identify Backups**. Establish backups for key personnel in the project. This ensures continuity of roles and responsibilities if a team member becomes unavailable.
- **Document Systematically**. Develop a unified documentation and data collection system within the team before. Regularly communicate updates and make sure everyone understands the system to ensure seamless knowledge flow.
- **Clarify Operational Rules.** Create clear, consistent operational rules and regulations for both project teams and study participants. Regularly communicate these guidelines to all parties involved.

To **prevent study participants from dropping out**:

- **Assign Dedicated Contact Person.** Delegating a specific person to maintain personal contact with study participants can improve engagement and reduce drop-out rates. This personal touch can include phone or face-to-face contact.
- **Automated Reminders**. Implement an automated SMS reminder system. Regular measurement reminders can help participants stay on track and engaged in the study.
- **Personal Contact with Participants.** Designate a team member to personally engage with study participants. This could take the form of regular check-ins, updates, or even casual conversations. Personal contact can foster a sense of connection and commitment, making participants less likely to withdraw from the study. It can also provide an opportunity for participants to express any concerns or issues they might have, enabling you to address them promptly.

The fluctuating project environment and uncertain external conditions were significant challenges. Nevertheless, the project team was adaptable and managed to meet the project objectives. Implementing the strategies above can further strengthen the project's resilience to such challenges in the future.

5.6. Limitations

Limitations worth considering within the design were due to:

External conditions:

A significant part of the project took place during the pandemic (2020), which, given the nature of the research, had a number of consequences.

Participation in the project involved physical repetitive presence in the laboratory, where participants had close contact with members of the research team (eeg, mri, Star Craft II training, testing). The lab team took care of the health safety of each person in the lab (temperature measurement, masks, disinfection, procedures, vaccination requirements).

Despite the precautions taken as a result of the pandemic:

- people who started participating in the project but did not finish it before the pandemic began withdrew from the project. Only some of them were ready to return to the project after the formal restrictions were reduced,
- partially exchanged the composition of the research team - not every person (due to the health safety of families, etc.) was ready for direct contact with participants

Given the complexity of the project and its nature, an important element of the project was the quality and reliability of the equipment and data collection systems. Although the failure rate can be assessed as not abnormal to the norm, but access to service or spare parts due to covid limitations was difficult, hence repairs took more time than standard. (see Appendix 2).

Limitations due to the specifics of longitudinal studies (cancellations between measurements).

Limitations due to the substantive complexity of the study and the large number of measurements: equipment failures, failures in recording some of the data, dynamics of involvement in the study by participants, technical mistakes by researchers.

A key limitation is the final number of subjects whose results were included. This number is due to the factors mentioned above, primarily the impact of the pandemic, while additional subjects could not be included. Each subject was required to devote about 100 hours to participate in the project, over a maximum of three months, for which he or she was paid 6 thou. if placed in the active group, and 3 thou. if in the passive group. When participants dropped out of the study (e.g., due to a pandemic or war), the project team had no way to pay for additional participants.

Distortions, related to the use of self-report questionnaires, particularly on flow, playability, or the NASA TLX questionnaire. Each of the aforementioned questionnaires was a repetitive element of the study, completed by the subjects multiple times (a maximum of 11 times), which could have caused frustration on the one hand and disrupted flow on the other, both of which affected responses and playability behavior.

In analyzing the data, it was decided that - due to occasional gaps in the data (e.g., cognitive or eeg tests) of individuals - each study would be analyzed autonomously, using the available data.

Diverse ways to study:

- games (different games)
- flow (different questionnaires)

Technical problems:

- technical problems with the Star Craft II servers between weeks 3 and 4 caused the measurements to be postponed by about a week
- the first resonance measurement took place without the last sequence in the scanner
- the last measurements final took place with large gaps between them
- measurements from block 4 did not take place as planned due to a non-functioning EEG
- equipment failure - equipment under repair - system died
- mouse failure

Problems related to renovations in the University building

- During the second and third BEH measurements, disturbances related to the renovation - sounds of drilling etc. (the person surveyed got distracted)

Problems, related to the behavior of the test subjects:

- interrupted Raven test (toilet break) followed by completion of the test in 30 minutes, interrupted gameplay (without turning off the timer)
- lateness, absenteeism from measurements, or multiple rescheduling of enrollment by the test subject, which posed serious challenges given the logistics of arranging assistants and booking studios
- random accidents, such as the rescheduling of a measurement block due to a car accident involving the subject
- changes in the subjects' plans (the subject is leaving)
- difficulties understanding basic mechanics and relationships in the game world (the subject required frequent prompts and used a sheet of paper with hints (regarding

mechanics, keys) until about the 30th hour of playing, the subject admitted to looking at support materials at home

Actions inconsistent with the study's objectives, resulting in loss of data fargments: forgetting to turn on the timer and pressing the end button before the session is actually over, subject scrolled through the information on the screen very quickly which resulted in prematurely ending the session in gex, before it was actually over, subject tended to click end session in gex while training was in progress, subject. subject accidentally closed the browser, resulting in lost gameplay, releasing empty gameplay (with no activity) on the running timer for longer than the gameplay time assumes, the subject does not keep his chin on the chin rest during the EEG test.

Problems arising from the war in Ukraine:

- the subject, due to the family situation in Ukraine, canceled the last measurement of the 2nd measurement block, which was scheduled to fall out
- withdrawal of study subjects and some assistants from the project due to the war in Ukraine (helping refugees, caring for family)

Problems related to the pandemic:

- numerous drop outs (individuals chose not to return to the project after the break caused by the lockdown and quarantine)
- due to quarantine postponed the last survey block by 2 weeks
- due to the quarantine of the subject extended the first training week by two weeks and shifted the measurement block
- postponements, due to infections of test subjects

Self-reports

A substantial body of psychometric research shows that measuring behavior through self-report can be highly unreliable, and that participants' responses are prone to cognitive, social and communication errors. Schwarz and Oyserman (2010) argue that "even seemingly simple behavioral questions represent complex cognitive tasks" for participants. In addition to question comprehension - which has been shown to affect the accuracy of answers, and changes in question wording, formatting or sequence affect results - the accurate recall of behavior is also affected by various cognitive limitations in autobiographical memory. These limitations are particularly pronounced for behaviors that are frequent and highly integrated into respondents' lives. This makes them difficult to isolate and accurately recall. Self-description of behavior is consequently an indicator of what respondents think they are doing - their perception of their own behavior - and not necessarily what they actually do.

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7. Appendix

No 1.

Basic descriptive statistics of the studied variables with the Shapiro-Wilk test

	M	*Me*	*SD*	*Sk.*	*Kurt.*	*Min.*	*Maks.*	*W*	*p*
Dispositional Flow Scale-2	122,91	127,00	17,51	-0,38	-0,48	85,00	154,00	0,97	0,219
Challenge-Skill Balance	13,79	15,00	2,77	-0,99	0,90	5,00	18,00	0,91	0,002
Merging of Action and Awarness	12,77	13,00	2,25	-0,31	-0,15	7,00	17,00	0,97	0,263
Clear Goals	14,17	15,00	2,94	-0,39	-0,25	7,00	20,00	0,95	0,065
Unambiguous Feedback	14,40	16,00	2,82	-0,68	-0,13	8,00	20,00	0,92	0,002
Concentration on the Task at Hand	14,17	15,00	2,45	-0,34	-0,75	9,00	19,00	0,94	0,018
Sense of Control	13,55	13,00	2,51	-0,45	-0,48	8,00	18,00	0,93	0,009
Loss of Self-Consciousness	12,40	12,00	4,53	-0,15	-0,77	4,00	20,00	0,96	0,124
Transformation of Time	13,60	14,00	3,19	-0,46	0,86	4,00	20,00	0,97	0,186
Autotelic Experience	14,06	15,00	2,94	-0,88	1,44	4,00	19,00	0,92	0,003
Flow State Scale-2	123,42	127,00	21,26	-0,58	1,08	36,00	179,00	0,94	0,022
Challenge-Skill Balance	12,31	12,00	3,41	-0,09	-0,61	4,00	20,00	0,96	0,150
Merging of Action and Awarness	12,21	12,00	2,92	0,02	-0,04	4,00	20,00	0,98	0,762
Clear Goals	14,28	15,00	2,90	-0,60	0,93	4,00	20,00	0,93	0,007
Unambiguous Feedback	14,33	15,00	3,05	-0,72	0,79	4,00	20,00	0,97	0,204
Concentration on the Task at Hand	15,16	15,00	2,51	-0,83	2,66	4,00	20,00	0,89	<0,001
Sense of Control	13,39	13,00	3,11	-0,31	0,01	4,00	20,00	0,96	0,168
Loss of Self-Consciousness	15,53	16,00	3,63	-0,64	-0,02	4,00	20,00	0,93	0,005
Transformation of Time	13,76	14,00	4,22	-0,35	-0,49	4,00	20,00	0,96	0,082
Autotelic Experience	12,44	13,00	3,72	-0,48	-0,38	4,00	20,00	0,95	0,044

The result of the Shapiro-Wilk test for some of the introduced variables turned out to be statistically significant, which means that their distributions significantly deviate from the normal distribution. However, it should be noted that the skewness of the distribution of these variables does not exceed the absolute value of 1, which means that their distributions are asymmetric to a slight degree. Therefore, it is reasonable to carry out the analysis based on parametric tests, provided that their other assumptions are met.

No 2.

Regulations for the operation of the NCRC in times of increased epidemiological risk

1. Only a healthy person, with no symptoms suggestive of an infectious disease, who does not reside in the quarantined person's home, may come to the study.
2. Before the study begins, the investigator will ask the subject to complete a questionnaire with four questions:
   A) Has the subject had a fever in the past two weeks?
   B) Has the subject had a cough in the past two weeks?
   C) Has the subject had shortness of breath in the past two weeks?
   D) Is there no person in quarantine at home?
3. Unnecessary items, including cell phones, should not be brought to the rooms in the laboratory where measurement procedures take place.
4. The researchers will provide a room where personal belongings (backpack, jacket, phone) can be left. This will be a specially designated room, locked.
5. Seating areas, touch surfaces, as well as used equipment (keyboard, mouse, headphones) will be disinfected before and after each use.
6. Laboratory rooms will be aired every 2 hours.
7. You can only bring to the lab with your own beverage bottle.
8. Before entering the laboratory, subjects will be asked to thoroughly disinfect their hands and put on gloves and researchers should wear gloves and visors and/or masks at all times. In addition, researchers will perform measurements in protective clothing - in interlining disposable aprons.
9. In the laboratory room there can be a maximum of 3 people - in the case of measurement sessions (2 researchers and 1 test person), if possible this number should be reduced to 2 (one researcher and one person).
10. During the measurement session, the test person will be allowed to spend the break between the research procedures only on the territory of the laboratory (without the possibility of going outside).
11. One measurement session will be allowed on a given day (only one person tested on a given day will be invited to the Laboratory).