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Neurocognitive Profile of Flow: Non- Effortful, More Precise and Broader Brain Circuits

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Abstract

Objective: This work aimed to understand in which extent neurocognitive literature supports and improves Csikszentmihalyi's [1] flow experience characterization, as a process dependent on attention and executive functions [2].

Methods: PRISMA systematic review included flow related observational studies that had presented neuropsychological, neurophysiological and/or biometric measures, addressing attention and executive functions: problem solving, response monitoring and decision making.

Results: Neuroscientific literature showed that flow experiences: a) activate non-effortful cognitive resources, with increased precision in visual focalized, divided and sustained attention, with evidence of its moderation by social factors; b) are indexes of higher problem solving skills, in non-validated measures; c) activate broad and differential brain activity during response monitoring (N-back) and risk taking (gambling) tasks, providing neurological indexes in line with our differential understanding of task meaning as an emotional and cognitive updating process, through corresponding brain circuits, involving basal ganglia, temporal, insular and prefrontal areas; d) has not yet been associated with decision making, in reviewed observational studies.

Conclusions: This work highlights the lack of interdisciplinarity in the field. Implementing neurocognitive strategies seems to be a potential psychological resource for reaching and optimizing satisfying moments. Broad community-based psychoeducation or training would expand daily life and work commitment.

Keywords: Flow; Optimal Experience; Neurocognition; Attention; Executive Functions; Systematic Review

Introduction

Meaningful tasks ought to be continuously expanded in one's work and everyday life, promoting joyful and successful moments. This continuously optimizing process has been described as flow or optimal experiences [1]. Flow has been described as a satisfying process in which one masterizes their skill, overcoming a challenge, and granting or improving meaning to such repetitive task.

Over time, literature has identified flow neurophysiological and biometric correlates. However, most of these studies in neuroscience have not addressed flow states through a neurocognitive approach. Instead, they've used games as evokers of optimal experience, describing neurophysiological measures of their subjective experience. As shown in Figure 1, those few works that addressed flow-related neurophysiological measures through cognitive tasks suggest that flow states promote more activation in ventrolateral prefrontal cortex and basal ganglia, as well as less activation or delayed latency in midfrontal and medial circuits [3-6].

Experimental designs of flow have massively used the challenge-skill balance paradigm to design their tasks, in order to measure flow. However, according to [1], the establishing process of flow occurs through cognitive resources, like attention, problem solving, response monitoring (goal- and rule-guided behavior), and decision making (refining choices over time) - which are highly studied in neuroscience [2]. Thus, this study aimed to review neurocognition literature (specifically, attention and executive functions) regarding flow experience.

Methods

This work aimed to understand in which extent neurocognitive literature supports and improves [1] flow experience theoretical characterization, more specifically, analyzing: a) attention; b) problem solving; c) response monitoring or self-regulation; and d) decision making. For answering this question, divided into 4 subquestions, a structured review was performed, following PRISMA guidelines, through the database combination recommended to reach >90% overall recall: Medline, Embase, Web of Science and Google Scholar (for this, the first 40 records have been selected) [7].

Studies have been collected through the following search expressions, in all aforementioned databases:

- "Attention" and ("flow experience" or "flow status");
- "Problem solving" and ("flow experience" or "flow status");
- ("Response monitoring" or "response supervision") and ("flow experience" or "flow status"); and
- "Decision making" and ("flow experience" or "flow status").

As response monitoring search did not retrieve up to 10 records in any database, the following expression was added: ("self-regulation" or "self-regulating" or "self-regulative") and ("flow experience" or "flow status"). All these search steps were posteriorly improved by citation searching of included studies [8].

Inclusion criteria considered observational studies that had presented neuropsychological, neurophysiological and/or biometric measures, addressing these attentional and executive functions. As article titles have become less explicit, as well as interdisciplinarity has reduced immediate identification of key study features through the abstracts, screening for eligibility has been done massively in a one by-one tracking approach. Exclusion criteria have been: animal or human disorder related sample; interventional; mathematical studies; referral to other flow processes (like nature, traffic or blood-related flow), as well as to other decision making/self-regulation concepts (like career choices or nonhuman automated processes).

Data collection process has been organized in Figure 1, 2 & 3. Double checking, comparing different tools (e.g. search results lists, folder lists, flow diagrams) was operated, summed to abstracts and references analysis, as the used method to prevent risk of bias in the included studies. At first, the reviewer downloaded, identified and screened the articles according to each search results list (retrieved on February 17th and 23rd 2024), double checking the data collection process, against duplicate, missing or additional files. Studies that were listed in two database searches, considering the same neurocognition function, have been treated as duplicate. Works that addressed two or more neurocognitive functions of interest were kept in each referred search results list, not having been considered as duplication. Additionally, citation searching provided more studies that would fit the inclusion criteria. Included studies remained grouped according to each neurocognitive function of interest. Later, through an analysis of their methods, the reviewer confirmed if the selected studies fit inclusion and exclusion criteria. Out of 729 works, a total of 10 studies have been eligible for this review.

Results have been synthesized, according to each studied neurocognitive function, under a conceptual analysis, in order to expand four core theoretical concepts regarding flow experience, listed in the Discussion section. Reporting bias and certainty assessment were provided by the reviewer' analysis, confirming that synthesized results incorporated or were coherent with all considered studies.

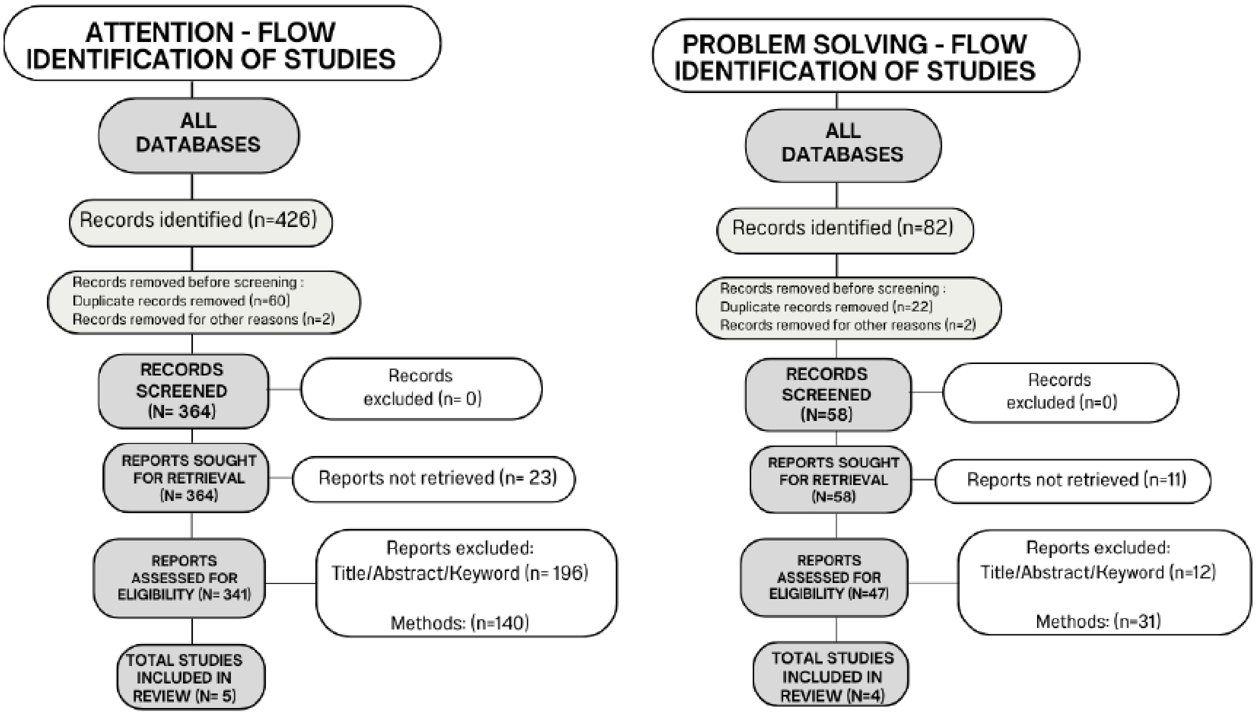

Figure 1: PRISMA 2020 Attention and Problem Solving - Flow Diagram. Adapted from Page, et al., and Alameda, et al.

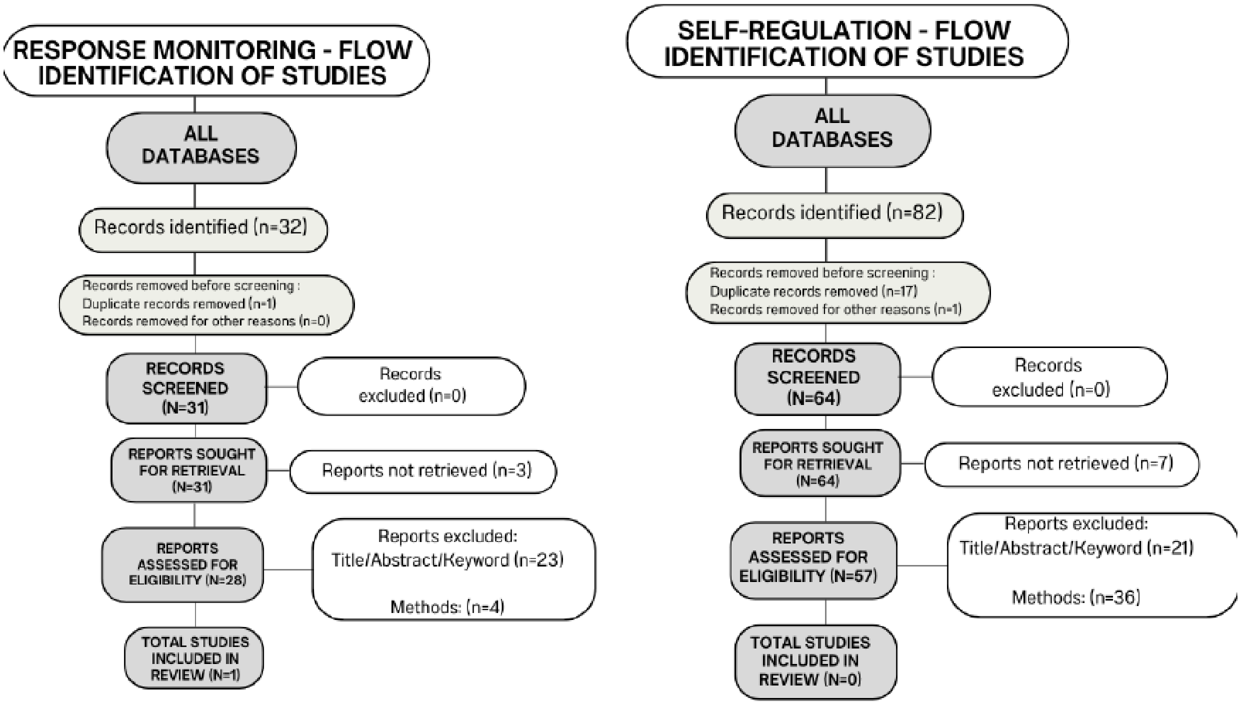

Figure 2: PRISMA 2020 Response Monitoring and Self-Regulation - Flow Diagram. Adapted from Page, et al., and Alameda, et al.

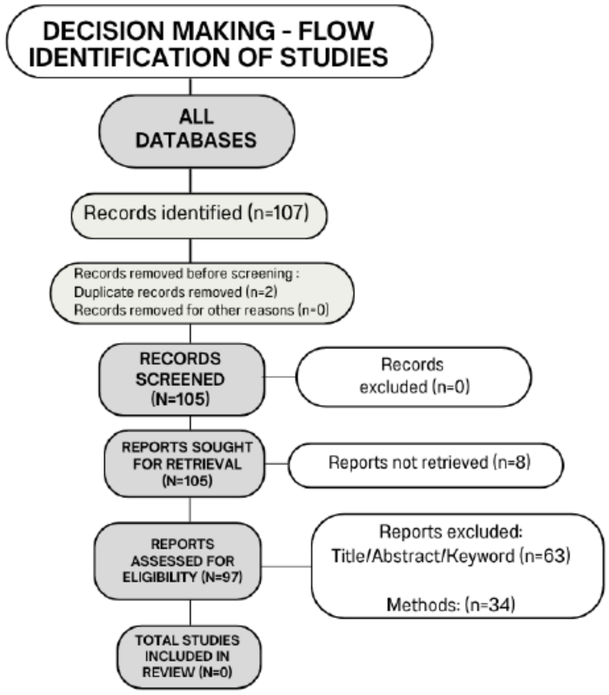

Figure 3: PRISMA 2020 Decision Making - Flow Diagram. Adapted from Page, et al., and Alameda, et al.

Results

Attention

Reviewed articles that inform about attentional processes during flow experience are listed in Table More efficacy in sustained attention, indexed by less comission errors in a long and monotonous task [9], has been associated with deeper effortless concentration report (a flow index) [10]. Response precision and Challenge-Skill Balance in the same task has been decreased when male would take a participant's body picture during the task, for those female participants with higher internalization of beauty ideals [11]. So, social factors interfere in the individual experience of flow and attention.

Thus, these flow studies invite an update on the neuropsychological characterization of attentional processes: they suggest that increased precision not necessarily means increased effort. Attention might be better described as an engaged (not effortful) allocation of cognitive resources.

Another work supports the non-effortful attribute of sustained attention under flow states (optimal challenge-skills balance). In a flow experimental procedure, using the classic non-verbal abstraction test, the Raven's Progressive Measures the ability of sustained attention skill (d2 Test performance) was only relevant and differential for trials with non-optimal challenge- skills balance [12].

In line with these results, another study used the challenge-skill balance in order to evoke and measure flow state. It showed that trials with a moderate attentional demand (Trail Making Test [TMT] B - divided attention subtask) evoked a perceived time distortion significantly different from trials with a low (Trail Making Test A – selective attention subtask) or high (adaption of Trail Making Test B) attentional demand. Thus, moderate attention trials (TMT B) have been used as a flow index. When attentional demands were moderate (versus low or high), the operational indicator of the flow state, perceived time distortion, was more sensitive than the self-report measure (which showed no statistical differences). Also, people who reported perception of challenge-skill balance (questionnaire flow index) for the TMT execution, showed better divided attention performance (measured by faster completion time) on the high-demand subtask, compared with those participants who did not perceive a challenge-skill balance [13]. Further studies, with pretest measures, might differentiate if these results inform that a) confidence increases cognitive performance (and consequently productivity), or that b) self-consciousness provides a more accurate perception of one's own performance.

One limitation that is shared by these attentional studies is that they do not measure flow experience with tasks that are meaningful for the participants. So, their flow concept is restricted to the challenge skill balance. Im SH, et al. [13] move forward and record an enjoyment measure, but it is related to the cognitive task, without correspondence to genuine daily life enjoyment.

Overcoming this limitation, Synnett S, et al. [14] performed a naturalistic observation of athletes and musicians during their specialized, flow- and joy-eliciting activity (sports or music performance), with a pre- and post- Temporal Order Judgment Task, which measures temporal processing and visual attention. Participants showed improved control of spatial attention with increased reported flow, suggesting that spatial attention was indeed positively modulated during flow experiences. Results indicate that a high level of reported flow reduces the distractibility from the central cues, measured by Point of Subjective Simultaneity (PSS) score, suggesting higher visual focalized attention.

Notably, none of the reviewed works studied the relationship between attention (as a neurocognitive function) and quality of experience, proposed by Csikszentmihalyi [1]. Enjoyment has been assessed by two works - directly, as a self-report [13], or indirectly, as inherent to a naturalistic experience (music/sports performance) [14]. However, results keep unclear regarding the proposed attention/quality of life association.

Thus, flow experiences activate non-effortful cognitive resources, with increased precision in visual focalized, divided and sustained attention, with evidence of its moderation by social factors.

It is also noteworthy that, among attentional studies, samples have been restricted to university students. Further studies might explore differential attentional aspects associated with flow states, according to different periods of life.

Study	Participants	Attention	Flow	Relevant Results
Guizzo F, et al. [11] (Italy)	107 Caucasian female university students: 18-31 years-old (X= 21.23 years, SD = 2.35). Sample included 71% University students (heterogeneously distributed among Law, Economics, Medicine, Psychology, Biology, and Engineering), 29% workers or unemployed; 90%	Sustained Attention to Response Task [9].	Flow Experience State scale [15] + Challenge-Skill Balance Subscale (proposed by [16])	Under male versus female gaze, higher internalization of beauty ideals [Sociocultural Attitudes Towards Appearance [17] were associated with lower challenge-skill balance (b = -.59, t = -3.30, p = .001, 95% LLCI = -.94, ULCI = -.23; Model: F (3,89) = 5.92, p = .001, R2 = .19), which in turn was related with decreased attention performance (b = .15.98, t = 4.35, p < .001, 95% LLCI = 8.68, ULCI = 23.28; Model: F (2,90) = 9.63, p < .001, R2 = .20).
Im SH, et al. [13] (USA)	50 Psychology university students: 27 females, 23 males (43 right-handed, 7 left-handed) 26.4 +- 6.9 years-old.	Adaptation of Trail Making Test: Low Demand: TMT 1	Flow Questionnaire (made by authors) after performing Specialized Activity: 5-point Likert scale for: perceived challenge, perceived skill, the balance between perceived challenge and skill, and enjoyment.	Flow self-reports (perceived challenge-skill balance): Group (p = .346) and individual (Q = 3.692, p = .158) analysis showed no differences in flow self-report, according to attentional demand.
				Perceived time distortion: Participants underestimated their completion times when attentional demands were moderate, more than when they were low F (1, 49) = 12.311, p = .001, η2 = .201 or high F(1, 49) = 7.787, p = .007, η2 = .137.
		Moderate demand: TMT 2	Perceived time distortion: the difference between the subjective time estimate and the objective completion time, normalized (i.e., divided) by the objective completion time.	Completion time: When attentional demands were high, the flow group (M = 119.3, SE = 4.6) had faster objective completion times (F(1, 48) = 6.554, p = .014, η2 = .120) than the nonflow group (M = 143.0, SE = 9.2).

		High demand: it added circles labeled with the first three letters of the months of the year. Participants must draw lines connecting 9 circles labeled with numbers, 8 with letters, and 8 with months in ascending order, switching between the three categories(e.g., 1-A-Jan-2-B-Feb- and so on).	Perceived time distortion: the difference between the subjective time estimate and the objective completion time, normalized (i.e., divided) by the objective completion time.	Enjoyment: At the group level, participants reported the greatest enjoyment when attentional demands were low, not when they were moderate as expected, F(1, 49 = 8.391, p = .006, η2 = .146 or high F(1, 49) = 5.360, p = .025, η2 = .099.
				At the individual level, however, participants in the flow state experienced greater enjoyment than those in the non-flow group when attentional demands were moderate F(1, 48) = 6.121, p = .017, η2 = .113 or high F(1, 48) = 6.024, p = .018, η2 = .112 than when they were low, as expected.
Marty-Dugas J, et al. [10] (Canada)	76 university students: 52 women, 24 men.	Sustained Attention to Response Task [9].	State: thought-probes. Three questions (7-point Likert scale) were presented at pseudo-random intervals during the SART task: “I got in the zone and didn’t have to force myself to concentrate” “I was able to completely focus without straining to pay attention” “I seemed to reach a level of deep focus almosteffortlessly”).	Reports of enhanced states of deep effortless concentration (thoughtprobes) during the SART were associated with fewer commission errors during the task, more marked in the second half (r(95) = − 0.27, p = 0.007) than in the first half (r(95) = − 0.27, p = 0.007).
			Trate: questionnaires. Deep Efortless Concentration Scale—Internal (DECI) and Deep Efortless Concentration Scale—External (DECE).	
			It indexes the frequency with which participants experience deep, efortless concentration during internal tasks, such as thinking and imagining (via the DECI; e.g., “I feel like I don’t have to force myself to keep fully engaged with my thoughts”) and external tasks, such as playing sports or instruments (via the DECE; e.g., “I get in the zone and don’t have to force myself to concentrate on the task I am doing”). Autotelic personality questionnaire.	

		d2 Test	Experimental task: Raven's ProgressiveMatrices divided into 4 groups, according to pilot participants' rating: low demand, optimal demand, high demand, low demand.	A statistically significant correlation was observed between d2 performance and experimental task (r = .25, p < .05). Further analyses showed rather similar correlations for individual trials (Low demands: .24, p < .05; High demands: .21, p < .05).
			State: Flow questionnaire (5-point Likert scale)	The correlation between d2 and average flow (questionnaire) was not statistically significant (r= .20, p = .07). However, the separate analyses by trial yielded a significant correlation between d2 performance and flow (questionnaire) for the High-demands trial (.26, p < .05).
		Point of Subjective Simultaneity (PSS) – spatial attention measure: It reflects the extent to which attention is distracted by a spatial cue, either peripheral (exogenous) or central (endogenous), such that the uncued side must be presented before the cued side in order for both stimuli to be perceived as having been presented simultaneously.	Activity Flow State Scale (AFSS): 5-point Likert scale, for the 9 dimensions of flow [Merging actions and awareness (MAA); Clear goals (CG); Concentration on task at hand (CO); Unambiguous feedback (UF); Challenge skill balance (CS); Transformation of time (TT); Sense of control (CN); Loss of self-consciousness (SC); Autotelic experience (AE)].	PSS – spatial attention measure: For every unit increase/decrease in experienced flow, the PSS improved/diminished by 21 ms, respectively, indicating improved control of spatial attention with increased flow (SE = 7.28, 95% CI [−35.58 to 7.05], t(227) = −2.93, p < 0.01).

Table 1: Attention and flow experience.

Problem Solving

Liu CC, et al. [17] detailed many problem-solving strategies involved in reported flow experience, through a problem solving computational game, in which the participant designs and builds their own rail systems. Participants who reported a flow state started using learning-by- example (tutorial reading) strategy. Also, they often applied a trial-and-error strategy.

Additionally, they also analyzed a solution before experimenting with it, demonstrating analytical reasoning for solving problems. However, the flow group strategy use showed no statistical difference, compared with the group that presented anxiety state during task execution.

In a small sample study (2 groups with 4 participants each), there were also no differences between solving problem tasks (maze or obstacle), according to self-reported flow after the task, as well as to other aspects of flow experience: challenge-skill balance, clarity of goals and feedback [18].

Supporting the challenge-skill balance characterization of flow experiences, improved performance along a virtual problem solving task has been associated to higher reports of flow experience after the task, in a cluster analysis [19]. Also, success in a problem-solving game (adaption of a Japanese crossword) had a positive association with the reported flow level and sense of control [20].

Thus, increased flow experiences are indexes of higher problem solving skills, in non-validated measures. It is noteworthy that despite assessing problem solving skill, none of the reviewed studies used a validated problem solving test or measure. Interestingly, they offer innovative methods, like immersive learning environment, robot-based and computational games, but these instruments have been presented without a proper analysis of their psychometric properties, like reliability, convergent validity and discriminant validity. Further studies might provide a more robust methodology, in order to validate their results and conclusions.

Study	Participants	Problem Solving	Flow	Relevant Results
Hou HT, et al. [19] (Taiwan)	67 university students: 50 female and 17 male 18 to 53 years-old (23.97 ± 6.26).	Boom Room game: a situated problem-solving context where students need to collect computer hardware by exploring the room and assemble a computer by manipulating the assembling simulation.	Flow Scale for Games [20]	Group (n = 18) with high prior knowledge – no improved performance group: demonstrated the highest game acceptance and experienced a medium flow state (3.71).
				Group (n = 18) with low prior knowledge – highly improved performance: medium levels of game acceptance and high flow state (3.86).
				Group (n = 31) with low prior knowledge – no improved performance group: demonstrated the lowest game acceptance and flow state (3.63).
Kiili K [20] (Finland)	221 participants from university community: 44% female and 56% male Age: 9% over 30 years old, 72% 21–30 years old, 14% 16–20 years old, 5% 11–15 years old.	Day off game: This adapted version of Japanese crossword was embedded within a story line that gives meaning to the puzzle to be solved.	Flow Scale for Games (adapted from Jackson SA, et al. [15]), a 5-point Likert scale.	Success in the game had a positive impact on the perceived flow levelt (219)=2.15, p = .03 (K-S d = .09) and sense of control t(219)=2.72, p < .00 (K-S d = .14).

Liu CC, et al. [17] (Taiwan)	117 first-year Computer Sciences university students.	TrainB&P: 3D computational game in which the participant designs and builds their own rail systems.	Learning Experience Survey: a 5-point Likert scale with two questions: "perceived challenge" and "perceived skills".	Students in the flow state demonstrated a problem solving strategy that mixed learning-by-example, trial- and-error, and analytical reasoning strategies.
			Flow group: balance of perceived challenge and skill.	
			Anxiety group: higher perceived challenge with lower perceived skill.	Compared with anxiety group, flow group presented no statistical differences in strategy use: solution development (t = -.53, p = .6); experiment (t= -.95, p = .34); solution review (t= .60, p= .55); solution reuse (t= 1.97 .052); or reading tutorial (t= .68 p=.50).
			Boredom group: lower perceived challenge with higher perceived skill.	
Schaikk V, et al. [18] (Japan, UK)	4 postgraduate students: 3 male, 1 female, from Yokohama University, Japan 20 ± 1 years-old.	Challenge-skill balanced Maze and Obstacle-course tasks: In maze problems, the teaching team had to design the course of a robot on the floor of their laboratory using adhesive tape.	Programmed version of a flow scale: flow scale measured three precursors of flow (clarity of goals, feedback, and balance of challenge and skill) and six dimensions of flow (concentration, perceived control, mergence of action and awareness, transformation of time, transcendence of self, and autotelic experience).	Self-reported flow was not associated with problem- type performance (R2= - 0.08, t = 0.77, p > 0.05). On the same line, precursors of flow did not vary according to problem solving task: challenge-skill balance (R2= -0.02, t = 0.13, p > 0.05), clarity of goals (R2= -0.08, t = 0.71, p > 0.05) or feedback ((R2= -0.06, t = 0.57, p > 0.05.
	4 postgraduate students: 3 male, 1 female, from Teesside University, UK 31 ± 5 years-old.	In obstacle-course problems, a configuration was given in which the robot had to navigate a course while achieving a predefined series of goals.		

Table 2: Problem solving and flow experience.

Response Monitoring

Literature is still scarce and the only work that addressed this relationship, considering our eligibility criteria, showed differential neural activation during the execution of response monitoring (Go/No Go) and gambling tasks, under flow state (challenge-skill balance). Results showed that flow (balanced-difficulty) conditions, compared to low- or high-difficulty conditions, revealed broad activity in brain structures associated with concept formation (dorsolateral prefrontal cortex; DLPFC), orienting attention (superior parietal lobes [SPL], precentral gyrus), and emotional processing (dorsoanterior insula) [21]. These results clarify about cognitive and affective dimensions of the updated task meaning when skill successfully matches challenge.

Also, under flow (balanced-difficulty) conditions, compared to low- or high-difficulty conditions, the bilateral nucleus accumbens (an anticipatory reward structure) showed functional connections with an extensive circuit implied in semantics, concept formation and response monitoring: the occipital pole, paracingulate cortex, central operculum, DLPFC, middle temporal gyrus, and temporal-occipital fusiform cortex [21].

The bilateral DLPFC seed exhibited connectivity with semantics (concept formation and comprehension) and response monitoring areas: the orbitofrontal cortex (OFC), frontopolar cortex, superior temporal gyrus (STG), central precuneus, and occipital fusiform gyrus, with several clusters extending into the anterior cingulate (ACC) and paracingulate (PCC) cortices. Seeding from putamen or thalamus did not provide significant results [21]. Flow adjustment features seem to be embased by basal ganglia and the DLPFC. Balanced-difficulty (but not high-difficulty) is differential to low-difficulty conditions in the activation of structures such as the DLPFC, putamen, caudate nucleus, dorsoanterior, and posterior insula [21].

As expected, flow (balanced-difficulty condition) showed less activity than low-difficulty condition in the Default Mode Network (DMN) structures, particularly the dorsal and ventral medial prefrontal cortex (PFC), ventral posteromedial cortex, temporal pole, and hippocampus [21]. These results support that flow is an actively engaged process, not automated. Finally, flow (balanced-difficulty) condition showed less activity than high-difficulty condition in the occipital fusiform gyrus, temporal pole, orbitofrontal cortex, and inferior temporal gyrus [21]. Lower frontotemporal-occipital circuit seem to be more implied in higher cognitive demand.

Study	Participants	Attention	Flow	Relevant Results
Huskey, et al. [21] (USA)	18 University students (fMRI) 87 University students (Asteroid impact experiment)	**fMRI ROI analyses:** N-back and gambling tasks. **fMRI neural activation:** Asteroid Impact game (developed by authors) -a point-and-click style video game where subjects used their cursor to collect targets that were displayed at C11different locations on a screen while avoiding distracting objects.	**Challenge-skill balance, incorporated to the Asteroid Impact game:** **Low-difficulty condition:** required subjects to collect three targets while avoiding just one object. **High-difficulty condition:** required that subjects collect 25 targets while avoiding seven objects of varying sizes that traveled at different speeds. **Balanced-difficulty condition:** incrementally increased difficulty by modifying four parameters: (1) the number of targets to collect, (2) the number of objects to avoid, (3) the rate at which objects moved, and (4) the size of the objects to be avoided.	**Flow (balanced-difficulty) conditions, compared to low- or high-difficulty conditions:** Broad activity in structures associated with cognitive control (DLPFC), orienting attention (superior parietal lobes; SPL, precentral gyrus), and attentional alerting (dorsoanterior insula). The bilateral nucleus accumbens showed functional connections with the occipital pole, paracingulate cortex, central operculum, DLPFC, middle temporal gyrus, and temporal-occipital fusiform cortex. The bilateral DLPFC seed exhibited connectivity with the OFC, frontopolar cortex, superior temporal gyrus; STG, central precuneus, and occipital fusiform gyrus, with several clusters extending into the ACC and PCC. Seeding from putamen or thalamus did not provide significant results.

Table 3: Response Monitoring and flow experience

Thus, flow experience showed to differentially activate dorsolateral and medial prefrontal, temporal and occipital fusiform cortices, supporting our understanding that sense of accomplishment and novelty provided by challenge-skill balance leads to an updated meaning, through a cognitive and affective update, with the activation of their neural circuits.

Decision Making

Up to our knowledge, flow literature has not developed yet observational studies that would analyse decision making. Possibly, this lack of neuroscientific reference is partially justified by the absence of clear reference to decision making as an inherent process towards flow acquisiton. However, when Csikszentmihalyi [1] states that increasingly refined choices are the way to reach specialization in a class of behavior, combined with progressive perceived success and enjoyment, the author indirectly positions decision making as part of the whole process that leads to optimal experiences.

Thus, decision making has not yet been associated with flow experience, in observational studies. Further studies would address flow-related decision making features.

Discussion

Recent neuroscientific literature is in line with Csikszentmihalyi's model of flow experience, confirming the importance of attention and executive function processes in order to improve the optimal experience.

Scarce literature has been interested in other than attentional cognitive process, regarding flow experience. Although attention, highlighted as psychic energy, is the cognitive aspect most emphasized by Csikszentmihalyi [1], this author also unravels the important role of other self-regulative functions, in order to achieve the establishment and constancy of the psychic dynamism characterized as a flow.

Literature regarding neurocognitive functions has been scarcely related to neurophysiological measures. More specifically, only one out of the reviewed neuroimaging studies analyzed neurocognitive skills not as a flow-evoking feature, but as an object of study. It denotes reduced interdisciplinarity in the incipient interest to understand flow from a neuroscientific approach. No studies have been reviewed informing about flow state biometric measures related to neurocognitive functions. Despite a recent broad interest shown in the high number of initial revised studies, well-designed works in neuroscience informing about neurocognitive functioning related to flow are still limited.

The majority (245 out of 570 works=43%) of the screened studies presented methodological instruments or paradigms lacking a conceptual framework regarding attention, problem solving, response supervision and decision making as cognition. Assuming that psychological processes are subjective or individual opinions, many works adopted self-reports or non-validated measures. So, they were not valid nor fidedign in their research, not providing a proper conceptual or methodological representation of attention and executive functions. However, literature in psychological processes is well consolidated, having reached refined methodological designs and standard validated measures, in a way that offers a clear understanding regarding differential features, components and steps inherent to the neurocognitive processes that precede behavioural measures. Flow interdisciplinary studies must benefit from neuropsychological literature, in a way to design conceptually coherent tasks and games, expanding their representation of psychological aspects. This observation unveils the importance of phylosophical reasoning for studies regarding the psychological phenomena, only available among specialists in the field. Positively, there is an increasing interest in applying flow concepts in order to enhance sales, teaching and gaming practices. However, these multidisciplinary studies lack, in their majority, an appropriate understanding regarding the studied psychological processes, resulting in invalid conclusions. Thus, in order to avoid ethical errors and to accelerate the business benefits from research results, innovative interdisciplinary studies need to go beyond applying instruments from other specialization fields. They truly need to integrate in their data analysis the phylosophy of science inherent to each specialization field, by incorporating to their team specialists, with their differential field reasoning, more than only their instruments.

Also, reviewed studies showed a limited conceptualization and methodological approach of flow, with a hyperfocus in the challenge-skill balance feature. Further studies should develop more sophisticated procedural designs, in order to benefit from Csikszentmihalyi's broad and integrated concept of flow experience.

Only one reviewed work assessed flow state during the task execution, specifically, a sustained attention task [10]. The inconvenience for this procedure is the potential for disruption of flow state, when interrupting task for the flow question. Schaik PV, et al. [18] suggested the incorporation of subtasks that would act as "milestones", measuring flow state within the cognitive task.

Indeed, a major limitation of the reviewed works, informing about flow-related attentional processes, is the analysis of flow experience as a time point of optimal experience. A flow model, in order to be valid as a driver for psychological changes (regarding wellbeing), needs to characterize processes, more than exclusively the manifested results. So, our second objective has been to provide a tool that might be helpful to design novel flow-eliciting tasks and paradigms, under a conceptually valid framework.

In general, this neurocognitive review has provided evidence for the implication of cognitive processes in the establishment of flow states. Literature has also provided neurological indexes of flow as an engaged (nonautomatic) process. Brain activation has also supported a differential understanding of task meaning as an emotional and cognitive updating under flow state, through corresponding brain circuits, involving basal ganglia, temporal and prefrontal areas. These interesting conclusions ought to be refined and expanded with much more well-designed neuroscientific studies. The reduced advances describing flow through a neurocognitive or neurophysiological approach might be partially attributed to the segmented nature of experimental models, summed to their simplified methodological representation of flow. As a limitation of our work, it does not include analysis of emotional aspects related to flow experience. As demonstrated by Huskey R, et al. [21], cognitive control and intrinsic reward processing share neurofunctional connections under flow state. Further versions of our proposed Work Flows task design might consider the intersection between neurocognitive and emotional features (as well as their neural connections), associated with flow experience.

Future initiatives must benefit from this model, which is expected to provide a solid and simplified reference for flow paradigms used in different neurotechologies, like virtual reality programs, neuromodulation and neuroimaging studies, in order to expand their clinical validity, shortening time to reach efficacy.

Conclusion

This work provides a confident analysis of neurocognitive literature regarding flow experience, ssociated with other neuroscientific measures. It highlights the lack of interdisciplinarity in the field.

Literature that reports flow-related attentional and executive functions processes, through neurocognitive tasks or paradigms, suggest that:

- Flow experiences activate non-effortful cognitive resources, with increased precision in visual focalized, divided and sustained attention, with evidence of its moderation by social factors.
- Increased flow experiences are indexes of higher problem solving skills, in non-validated measures.
- Flow experience revealed broad brain activity during response monitoring (N-back) and risk taking (gambling) tasks, providing neurological indexes in line with our differential understanding of task meaning as an emotional and cognitive updating process, through corresponding brain circuits, involving basal ganglia, temporal, insular and prefrontal areas.
- Decision making has not yet been associated with flow experience, in observational studies.

So, neuroscience literature confirms that higher neurocognitive skills, specifically attention, problem solving, response monitoring/self-regulation and decision making - mentioned in Csikszentmihalyi's [1] flow concept - are significantly associated with achieving higher flow state or optimal experience. Much has been recently published regarding the interaction between neurocognitive self-control and other wellbeing measures, like self-compassion, mindfulness, hope and life satisfaction [22-24]. Implementing neurocognitive strategies seem to be a potential psychological resource for reaching and optimizing satisfying moments. Broad community-based psychoeducation or training would expand daily life and work commitment [25-29].

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