InterFlowCeption: Foundations for Technological Enhancement of Interoception to Foster Flow States during Mental Work

About the potential of technologically supported body awareness to promote flow experiences during mental work

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ABSTRACT

Conducting mental work by interacting with digital technology increases productivity, but strains attentional capacities and mental well-being. In consequence, many mental workers try to cultivate their flow experience. However, this is complex and difficult to achieve. Nevertheless, current technological systems do not yet provide this support in mental work. As interoception, the individual bodily awareness is an underlying mechanism of numerous flow correlates, it might offer a new approach for flow-supporting systems in these scenarios. Results from a survey study with 176 digital workers show that adaptive regulation of interoceptive sensations correlates with higher levels of flow and engagement. Additionally, regular mindfulness practices improved workers' adaptive regulation of bodily signals. Based on these results and integrating the current literature, this work conceptualizes three future technological support systems, such as interoceptive biofeedback, and electrical or auditory stimulation to enhance interoceptive awareness and foster flow in mental work.

CCS CONCEPTS •Human-centered computing •Human computer interaction (HCI) •Empirical studies in HCI

KEYWORDS

Mental Work, Flow Experience, Work Engagement, Body Awareness, Interoception, Technological Support Systems

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1 INTRODUCTION

Using digital technology is ubiquitous in everyday work life. Worldwide, a rising number of employees, freelancers, and students are interacting with mobile computers or workstations, especially when conducting mental work [67–69]. Unfortunately, these developments are often accompanied by detrimental side effects such as fatigue [19, 25], stress, or reduced job satisfaction [43]. In consequence, the need for digital technologies to foster advantageous mental states tremendously increases in digital work scenarios, not only for increasing productivity but also for the well-being of body and soul [43]. An optimal mental work experience is characterized by a constant task focus that goes along with being totally absorbed by a fluently performed activity. The experience of flow represents such a desired mental state [50]. In addition to ideal performance, flow during work is also accompanied by emotional comfort, high levels of intrinsic motivation [1], and the absence of work-related mental symptoms characteristic of a burnout disorder [3]. Moreover, flow states are highly efficient regarding the investment of energy and effort during work [54]. Taking this into account, flow is an invaluable state of mind during digital mental work. Therefore, understanding, detecting, and fostering how intensively someone is fully engaged in a task has been and remains a desirable and also ambitious research goal. So far, scholars primarily focused on the technological detection and promotion of flow states in adaptive game design and learning settings. By increasing immersion or adapting the difficulty of a task, they improved the user's experience during technology interaction [2, 8, 40, 49, 58]. As these methods are not applicable in the context of real-life mental work, finding new digital solutions to foster flow states during mental work is still an open research goal.

At this point *interoception*, the human sense of internal body sensations can be a novel and so far, underexplored approach to facilitate flow states. Although multiple established flow correlates such as emotions or intrinsic motivation are based on interoceptive processes [13, 23] there is surprisingly little research related to interoception as a potential factor in the experience of flow [17]. This appears even though the importance of bodily sensations during flow has already been highlighted in early flow measures and contemporary flow research in various contexts [26, 32]. Further, multiple research has demonstrated that an individual's interoceptive capabilities can be supported with classical mindfulness practices and also via interactive technological support, e.g. meditation in virtual realities or neuromodulation [28, 29, 38, 64]. In consequence, technological support of a human's interoception might be a new and promising approach to foster flow states, generally and in specific during digital mental work. To explore this potential, the following research question needs to be investigated: *Is individual awareness of bodily signals linked to the amount of flow experience, work engagement, and well-being in digital mental work scenarios?*

To answer this research question a comprehensive online survey ($N = 176$) was conducted. Based on the preliminary survey results this work contributes to the theoretical and practical field on several levels. First, the initial results of this study support the idea of a correlational relationship between interoceptive awareness and a person's disposition to experience flow, engagement, and well-being in the context of mental work. Second, as miscellaneous facets of participants' interoceptive awareness differed depending on the frequency of practicing mindfulness, this may build the formation of technological support systems for user-specific recommendations or interventions to foster flow states during mental work. Third, conceptualizing and discussing new approaches for technological support of interoceptive awareness and flow provides particular system designs for the following research steps.

2 RELATED WORK

2.1 The Experience of Flow

Flow is a mental state of complete absorption and effortless action during an inherently motivating activity [21]. More comprehensively, flow can be described by nine typically reported characteristics: (1) fusion of action and consciousness, (2) high task focus, (3) reduced self-referential thinking, (4) feeling of control, (5) clear task goal, (6) continuous feedback of performance, (7) intrinsically rewarding activity, (8) altered experience of time and (9) optimal match of skills and task demands [42]. Multiple studies have shown that flow is linked to a variety of beneficial outcomes like optimal task performance, enjoyment, positive emotions, well-being, and personal growth [10, 21]. Therefore, scholars from different fields consider flow as a highly relevant state of mind and a key construct in terms of positive psychology [15]. Importantly, flow is not only experienced during enjoyable leisure activities but also during work [14, 18, 20].

Besides non-technological approaches to foster flow experiences (e.g., mindfulness practices, active imagery, hypnosis) that are often used in sports [66], the availability of established technological systems to foster flow is limited. One category of support systems is based on the absorption aspect of flow and increases a user's immersion by enriching the interactional context, e.g. during gaming or art activities [31, 41, 46, 49, 52, 63]. Another system category applies the flow theory of an optimal balance between skills and task difficulty. Here, various technical approaches of difficulty adjustment are used, e.g. player matching or adaptive difficulty adjustment [2, 22, 39, 40, 53]. Further, technological systems also modify the ratio of reward and task effort. This is also used in adaptive game design or learning settings [16].

As described, the beforementioned technological methods are contextually limited to gaming, learning, and art activities. Consequently, they are not applicable in real-life mental work settings. Thus, despite a large amount of flow-related research, finding new technological solutions in the scope of efficient adaptive technologies to support flow states during mental work is still an open and highly relevant research goal.

Although the relevance of bodily sensations during flow has already been mentioned in multiple contexts [6, 11, 32] and was used within initial flow questionnaires (*"My mind isn't wandering. I am not thinking of something else. I am totally involved in what I am doing. My body feels good."*), research on the connection between bodily awareness and flow is sparse [26, 32]. Therefore, in this work, we propose novel approaches for adaptive technological flow support that is based on the potential interplay between flow experience during mental work and the individual awareness of bodily sensations, namely interoception.

2.2 Interoception: The Sense of the Inner World

Perceiving the internal bodily state or having an emotional experience is impossible without interoceptive processes. Interoception is the gateway to a human's inner world and includes all activities of the central nervous system that sense, interpret and integrate corporal signals [36]. It represents a fundamental mechanism of multiple and well-established flow correlates such as bodily well-being, emotional experience, absence of psychopathology, intrinsic motivation, and an altered sense of time [13, 23, 36, 37, 65]. Furthermore, it is a complex and multidimensional construct of the brain-body-communication, that is prominently based on the vagus nerve as a major communication pathway [7, 51].

Multiple measures exist to quantify the interoceptive characteristics of a person [48]. Checking the accuracy of silently counting the own heartbeat, also known as the heartbeat perception task, is one of the most prominent objective features of interoceptive sensitivity [59]. Scholars from clinical psychology found several connections between interoceptive sensitivity for the own heartbeat and emotional experiences or mental difficulties, e.g. higher sensitivity scores in anxious persons or panic disorder patients [37]. Also, several questionnaires represent established approaches to extensively describe a person's subjective perspective on their body awareness via specific subscales of interoceptive awareness [45]. A common clustering approach differs into maladaptive versus adaptive interoceptive awareness and also into awareness versus regulation of interoceptive sensations from the body [27].

Even though interoceptive characteristics are dispositional personality traits of an individuum, they can change over a lifetime and are intentionally malleable via various training methods. Among others, classical mindfulness-based approaches such as meditation or active body relaxation (e.g., yoga, qigong) can effectively manipulate individual interoceptive awareness [24, 38, 64]. Furthermore, research has already demonstrated that an individual's interoceptive abilities can also be supported via interactive technologies [28–30].

Table 1: Structure of MAIA-2 questionnaire [27, 45]

Cluster	MAIA-2 Subscales [a]	Short Description
Maladaptive Interoceptive Awareness	Not-Distracting	not ignoring or distracting from bodily sensations
	Not-Worrying	not worrying or being distressed by pain or discomfort
Adaptive Interoceptive Awareness	Noticing	awareness of body sensations
	Emotional Awareness	awareness of the connection between body and emotion
	Body Listening	active listening to the body for insight
Adaptive Interoceptive Regulation	Attention Regulation	ability to sustain and control attention to body sensations
	Self-Regulation	ability to regulate distress by attention to body sensations
	Trusting	experience the own body as safe and trustworthy

[a] An overall sum score for the MAIA-2 questionnaire is not defined.

Combining all this, technological support systems to manipulate and enhance individual interoceptive abilities might represent novel and promising approaches for real-time flow support, in general, and especially when conducting mental work.

Grounded on the exploration of the aforementioned research question, this work proposes novel concepts of flow support systems based on the technological enhancement of the individual interoceptive body awareness.

3 METHOD

To investigate the relationship between interoceptive awareness, flow experience, work engagement, and well-being during mental work an explorative online survey was conducted. The survey was pre-registered and approved by the committee for data protection and ethics of the institution of the first author. The survey was structured as follows.

After giving informed consent participants confirmed that their current main occupation was based on a digital mental work context. For this purpose, several representative mental work scenarios including silent interaction with a digital device were illustrated such as learning, programming, concept creation, or analyzing data (e.g., *"Students are doing mental work while silently learning for an exam or writing their final thesis.", "Scientists are doing mental work while silently planning an experimental setup or analyzing data.")*. The essential main part of the survey consisted of completing multiple questionnaires. Subjects were invited via different online platforms. The survey was conducted in English and lasted approximately 15 minutes.

3.1 Sample Description

Based on a-priori sample size planning with the assumption to explore small correlations ($r \geq .2$), 208 participants completed the online survey. A subsequent data cleanup procedure comprised the following exclusion criteria: age limits, sufficient knowledge of the English language, correct answers to all control questions, explicitly confirmed conscientious participation after the survey, overall time duration, and distracting application changes below a limit of three standard deviations related to all completions. A final sample of $N = 176$ participants remained after the removal of invalid completions. Participants' age ranged from 18 to 47 years ($M = 25.74$, $SD = 4.34$). The majority of the sample (54.5% female, 43.8% male, 1.7% diverse or no reply) reported having an academic degree (66.5%) or at least a high school diploma (30.0%). Most participants were students (73.3%) and employees or self-employers (24.4%).

3.2 Survey Design and Measures

The following instruments were applied in the survey. General interoceptive awareness was measured via *Version 2 of the Multidimensional Assessment of Interoceptive Awareness questionnaire (MAIA-2)* with 37 items [45]. The MAIA-2 is a well-validated and comprehensive instrument for self-reported interoceptive awareness. It consists of three clusters, namely maladaptive interoceptive awareness, adaptive interoceptive awareness, and adaptive interoceptive regulation which consist of two or three subscales respectively [27]. Table 1 illustrates the subscale-cluster-allocation including a short description of each MAIA-2 subscale.

To address the explorative aspect of the survey the disposition to experience flow in participant's work scenarios was assessed via two questionnaires, the 10-item *Flow Short Scale (FSS)* [21] and the 9-item *short form of the Dispositional Flow Scale-2 (SDFS-2)* [33]. Next to a sum score for flow experience the FSS also measures the subscales *fluency of performance* and *absorption by activity*. In addition, the 9-item *short form of the Utrecht Work Engagement Scale (UWES-9)*, an instrument for measuring work engagement and well-being during work, was applied particularly to participants' individual mental work scenarios [60]. Via the 20-item *Positive and Negative Affect Scale (PANAS)* general personality traits to experience positive and negative emotions were assessed by two independent subscales [62]. As control variables, sociodemographic data (age, gender, skills in English language, education, occupation) were collected. Participants were also asked about frequency and type of their mindfulness practices in case of exercising regularly (several times per week).

4 RESULTS

4.1 Statistical Analysis

All scales and subscales showed at least acceptable or even superior internal consistency levels with Cronbach's Alpha raw values of 0.7 or higher. Moreover, a confirmatory factor analysis of the MAIA-2 questionnaire, evaluating various fit indices, revealed an at least acceptable or even superior fit of the survey data with the supposed model structure of the questionnaire. Expected convergent validity among all flow and work engagement related measures was

Table 2: Correlation matrix (N = 176) with Bonferroni adjusted alpha level

MAIA-2 Subscales	FSS (sum)	FSS (fluency)	FSS (absorption)	SDFS-2 (sum)	UWES-9 (sum)	PANAS (positive)	PANAS(negative)
Not-Distracting	.15	-.07	-.23	-.13	-.09	-.06	-.11
Not-Worrying	.02	.03	0	.01	-.12	.02	-.19
Noticing	.25	.22	.22	**.27***	**.29***	.19	0
Emotional Awareness	**.35***	**.33***	**.27***	.24	**.35***	**.27***	.01
Body Listening	.19	.23	.08	.19	.22	.21	-.06
Attention Regulation	**.30***	**.32***	.18	**.33***	**.25***	.23	-.18
Self-Regulation	**.33***	**.38***	.16	**.32***	**.31***	**.27***	-.19
Trusting	**.40***	**.45***	.19	**.38***	**.39***	**.37***	**-.38***

* ***p* < .0009** (Bonferroni adjusted alpha level)

confirmed by highly significant correlations with $r = .67$ ($p < .001$) or stronger without exception. Also, the PANAS positive affect subscale confirmed convergent construct validity by significant correlations with $r = .45$ ($p < .001$) or stronger with all flow and work engagement related measures without exception.

4.2 Correlation Matrix

To address the multiple comparisons and avoid an impermissibly high false positive rate within the significant correlations, the significance level was adjusted by using a restrictive Bonferroni correction with a number $k = 56$ of all reported correlations [34]. Applying the adjusted alpha level reveals the correlational patterns illustrated in Table 2. Multiple significant correlations were found among subscales of self-reported interoceptive awareness and on the other side, self-reported flow experience and work engagement in participants' individual work context. Following the previously mentioned subscale-cluster-allocation of the MAIA-2 questionnaire both adaptive clusters showed multiple correlations with flow and work engagement related scales. In terms of the adaptive interoceptive awareness cluster (Noticing, Emotional Awareness, Body Listening) a pattern of irregularly occurring correlations was found. Particularly, the adaptive interoceptive regulation cluster (Attention Regulation, Self-Regulation, Trusting) revealed consistently significant correlations with both flow scales, the flow fluency subscale, and the work engagement scale. This cluster also showed significant correlations with the PANAS subscales. Overall, the Trusting subscale has the strongest correlations with flow, engagement, and well-being during mental work and is also strongly correlated with both PANAS scales. No significant correlations occurred within the maladaptive interoceptive awareness cluster (Not-Worrying, Not-Distracting).

With a cluster-based view, the results can be summarized as follows: participants who reported higher levels of adaptive interoceptive regulation also reported higher levels of flow experience, fluency in performance, work engagement, and well-being in their digital mental work scenarios. Higher levels of adaptive interoceptive regulation are characterized by a higher ability to sustain and control attention to body sensations, a higher ability to regulate distress by focusing attention on body sensations, and a pronounced perspective of the own body as a safe and trustworthy place.

4.3 Manipulation of Interoceptive Awareness

Asked for frequency and type of their mindfulness practices, 45.5% of all participants reported to never exercise. Another 45.5% reported irregular exercises (less than weekly). The remaining 9.1% exercised regularly (several times per week). To test if interoceptive awareness differed depending on the frequency of practicing mindfulness, one-way ANOVAs were calculated for each MAIA-2 subscale after assessing normal distribution and variance homogeneity requirements. All subscales belonging to either the adaptive awareness cluster (Noticing: $F(2,173) = 5.81$, $p < .01$, Emotional Awareness: $F(2,173) = 7.67$, $p < .001$, Body Listening: $F(2,173) = 8.63$, $p < .001$) or the adaptive regulation cluster (Attention Regulation: $F(2,173) = 8.17$, $p < .001$, Self-Regulation: $F(2,173) = 18.76$, $p < .001$, Trusting: $F(2,173) = 3.06$, $p < .05$) revealed significant group differences. Additionally, Tukey tests for each subscale of both clusters confirmed significantly higher means in participants exercising regularly compared to those who never exercised. This indicates that adaptive interoceptive awareness differed according to the frequency of practicing mindfulness.

Reports of regular mindfulness practices are shown in Table 3. Next to conventional practices (e.g., yoga, breathing techniques) some participants explicitly reported the use of technological support such as smartphone applications (e.g., 7Mind, YouTube) or specific sound triggers (e.g. ASMR sounds), showing an existing potential for technological enhancement and stimulation of adaptive interoceptive awareness.

5 DISCUSSION

The results of this late-breaking work indicate that participants with a stronger adaptation on their internal body signals, namely adaptive interoceptive regulation, also experience more flow, higher fluency of performance, higher work engagement, and well-being during digital mental work. As interoceptive regulation is related to higher abilities in sustaining attention to body sensations, regulating distress by focusing attention to body sensations, and a stronger extent of perceiving the own body as safe and trustworthy, it seems promising to stimulate particularly these adaptive interoceptive abilities to foster flow states simultaneously during mental work.

Furthermore, subjects regularly practicing any type of mindfulness exercise reported higher adaptive interoceptive awareness and

Table 3: Reported mindfulness practices in case of exercising regularly (N = 16)

Conventional Mindfulness Practices	
"Qigong, mindful awareness, instrument meditation"	"Yoga" [b]
"Breathing technique"	"breathing techniques, Yoga"
"PMR"	"MBSR, Aware Walking/Eating/Breathing/..."
"Riding a bike"	"Going for a walk"
Practices with Technological Support	
"I do guided meditations with 7mind"	"guided meditation"
"But only if listening to ASMR counts - otherwise I do not"	
"guided meditation through YouTube videos and concentrate on breathing"	

[b] Five participants reported "Yoga" as their regular mindfulness practice.

regulation compared to those who did not. This relationship is in line with established theory and empirical findings of research on interoception [9] and has already been applied by scholars in the field of human-computer interaction, such as smartphone-assisted meditation or meditation in virtual realities [29, 30]. In addition, within the reported types of regular mindfulness practices, several exemplary approaches for technologically supported interoceptive awareness might be found. However, these technologies were exclusively applied with a focus on momentary mindfulness, i.e. they were not used during mental work as a simultaneous intervention method. Future work may use these results to design systems for technological interventions to foster flow by supporting adaptive interoceptive abilities. Additionally, they could test if individual personality traits of interoceptive awareness can be used as predictors for the system's effectiveness. Finally, this work contributes to these next steps by conceptualizing and discussing dedicated system designs.

6 OUTLOOK: TECHNOLOGICALLY-SUPPORTED BODY AWARENESS TO FOSTER FLOW IN MENTAL WORK

Based on the survey results and applying the current state of research, three exemplary approaches for technological support systems to stimulate and enhance interoceptive awareness to foster flow states during mental work are presented. These three examples build on current state of research findings which show promising results for stimulation of interoceptive awareness. Diverse methods with different principles of stimulating and enhancing body awareness were selected because a comparison of these principles in terms of their flow-promoting effects is not available yet. Further, when conceptualizing these systems, not only existent literature but also pragmatic aspects were considered, following the assumption that a wearable system design is of utmost importance to ensure everyday life practicability. Also, all support systems should offer the users quick and simple adaption of the output signal amplitudes to an almost unconscious subliminal level. This could be done immediately after system startup and ensures that flow states are not negatively affected by the work irrelevant stimulation signals and also addresses daily volatilities of a user's perceptional sensitivity.

Interoceptive Biofeedback is based on the principle of enhancing interoceptive awareness by delivering an external stimulus that depends on or is synchronized to an internal state or function of the body. Such a technological support system could detect e.g. the heartbeat or heartbeat variability and transfer a corresponding signal to one or multiple sensory channels of the user (e.g., optical, acoustical, tactile). Interoceptive Biofeedback has already been used in clinical settings to reduce anxiety by improving sensitivity to the own heartbeat [57]. Also, non-clinical settings showed a reduction of anxiety and stress by applying a heartbeat-based tactile feedback device in the context of public speech anticipation [61]. Furthermore, technology for the transfer of interoceptive sensations to other participants during remote social interactions contributed to increased feelings of connectedness between participants [47]. Therefore, it seems consequent to propose a technological support system for interoceptive biofeedback training to positively impact the flow state of a person. This idea is additionally supported by the fact that flow states occur especially during moderate arousal combined with relaxation [42, 55]. Figure 1 (left) illustrates a device for tactile feedback of the own heartbeat applied via a wristband.

Transcutaneous auricular Vagus Nerve Stimulation (taVNS), the second proposal for a flow-promoting system, relates to the principle of directly enhancing nerval activity via an electrode attached to the ear. As mentioned before, the vagus nerve has a prominent role in transferring interoceptive signals between the brain and the body. The taVNS method originates from clinical research (e.g., depression, headaches, migraine) and aims to foster relaxation, which is beneficial to get into states of flow [42]. Noteworthy, there is already empirical evidence for taVNS affecting both, interoceptive abilities [51] and flow experience [12]. Applying taVNS simply requires an electrode that is attached directly to a branch of the vagus nerve on the user's auricle as shown in Figure 1 (middle). Due to its benefits this easily applicable, non-invasive, and safe technique has become a more and more popular method in research and might be an upcoming standard in real-life applications of neuromodulation, also for healthy subjects. Next to the electrode, taVNS only requires a small and lightweight ($\leq$ 120 g) device to trigger an electrical stimulation signal. Subjects can autonomously activate these devices by a simple application to start and stop predefined stimulation programs. As these wearable

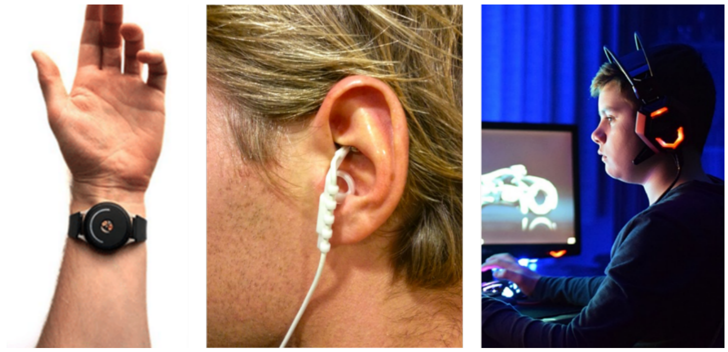

Figure 1: (from left to right): tactile biofeedback device [61], applied taVNS-electrode [35], set up for acoustical stimulation of ASMR sensations (https://pixabay.com/de/photos/kind-spielen-spiel-technologie-3264751)

devices have already been used in real life scenarios, the adaption on a persons' subliminal perception level could be easily provided.

Acoustically triggered Autonomous Sensory Meridian Response (ASMR) is the final proposal for a support system. It is derived from participants' reports about regularly used technological support that supplies an external, not body-related signal with a proven relaxation effect. ASMR describes a complex phenomenon of pleasant and relaxing body sensations, typically starting with a tickling on the scalp and continuing downwards via spine and shoulders [44]. ASMR can be triggered by various stimuli, among others via dedicated sounds such as whispering, crisp sounds, and tapping fingernails [70, 71]. It does effectively contribute to higher relaxation. A link between the number of various applied ASMR triggers and reported flow has already been shown [4]. Scholars also emphasized a potential overlap of ASMR experiences and flow in terms of deep relaxation and well-being [5]. Furthermore, researchers found stronger responses to ASMR in subjects with higher interoceptive body awareness [56]. Thus, promoting flow during mental work by using a system to acoustically trigger ASMR sensations seems consequent. This again offers all advantages of a wearable device that can be individually adapted in terms of comfort and signal amplitude. As ASMR sounds are freely available on various platforms they can be accessed and used easily via smartphone and headset during everyday mental work as shown in Figure 1 (right).

In a nutshell, this work presents initial support for a relationship between interoceptive awareness and flow experience during mental work. Based on participants' feedback and current literature three design proposals for technological flow support via stimulation of interoceptive awareness were conceptualized and discussed. This might constitute a foundation for novel flow-promoting technology to improve productivity and well-being during everyday digital mental work.

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