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At the Heart of Optimal Reading Experiences: Cardiovascular Activity and Flow Experiences in Fiction Reading

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ABSTRACT

Fiction reading is a popular leisure activity associated with a variety of pleasurable experiences, including suspense, narrative transportation, and—as indicated by recent empirical studies—also flow. In the context of fiction reading, flow—generally defined as a pleasurable state of mind experienced during an optimally stimulating activity—is specifically related to an optimal balance between text-driven challenges and the reader's capabilities in constructing a mental story model. The experimental study reported here focused on the psychophysiological underpinnings of flow in the reading context. Cardiovascular data were collected from 84 participants both during a relaxation baseline prior to reading and during reading. Participants were randomly assigned to read one of three versions of a chapter from Homer's *Odyssey*. According to statistical readability indices, these versions were low, intermediate, or high in readability, and hence in cognitive challenge. Flow was measured immediately after reading with a self-report scale that was tailored to assess reading-specific flow experiences. Regression analyses revealed that cardiovascular activation patterns measured before reading that are reflective of parasympathetic dominance—that is, an inner state associated with relaxation and cognitive fluency—moderated flow experiences during reading. In line with the stipulations of flow theory in regard to matching challenge levels being the key determinant for flow, this pattern supported subsequent flow experiences only in response to text versions of high or intermediate, but not of low cognitive challenge. Differences in cardiac vagal tone during reading were, however, not sensitive to our experimental modifications and not predictive of flow experiences.

In his essay *Moments during Reading* (1932), the German journalist and writer Kurt Tucholsky noted:

> At times, oh joyous moments, you immerse yourself in a book so deeply that you completely disappear into it – you cease to exist. Heart and lungs are functioning, your body steadily does its inner factory work – you don't feel it. You know nothing of the world surrounding you, you don't hear a thing, you don't see a thing, you read. You are under the spell of a book." (Tucholsky, 1932, p. 573)

As illustrated by this quote, positive reading experiences are typically characterized by a state of deep involvement with the fictional world. To achieve this, the reader needs to construct a vivid mental model of the text (see McNamara & Magliano, 2009, for an overview over mental model theories in reading research). This task requires considerable mental effort, as the reader has to parse the text to gather information, integrate it with his or her pre-existing cognitive schemata, and form appropriate mental representations (Buselle & Bilandzic, 2008). According to the *event-index*

INTERNATIONAL LITERACY ASSOCIATION

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model theory (Zwaan, Langston, & Graesser, 1995; Zwaan & Radvansky, 1998), these mental representations are then stored in *situation models* (van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998) that are organized along the dimensions of time, space, protagonists, causality, and intentionality. Yet, as Tucholsky describes, during a positive reading experience, the reader is oblivious to these mentally demanding processes that underlie what is subjectively perceived as a purely pleasurable and relaxing activity (Buselle & Bilandzic, 2009; Green, Brock, & Kaufman, 2004; Nell, 1988).

Reading research has proposed a plethora of theoretical concepts in relation to positive reading experiences, with *immersion* (Murray, 1997), *presence* (Gerrig, 1993), *narrative transportation* (Green et al., 2004), *narrative engagement* (Buselle & Bilandzic, 2009), and *story world absorption* (Kuijpers, 2017) being the most prominent ones. Whereas immersion and presence both refer to a sense of being in the story world, the latter three involve imaginary as well as attentional, cognitive, and emotional components. Beyond their differences in regard to particular aspects of readerly involvement, all these concepts rely on the reader's successful construction of a vivid, multifaceted mental model of the story. This close link between the way a narrative is experienced and processed is also illustrated by findings from narrative persuasion research: For instance, readers who experience more transportation into a story world are at the same time more prone to processing the text less critically (Appel & Richter, 2007; Green, Garst, Brock, & Chung, 2006).

Notwithstanding, the rich theory behind pleasurable reading experiences, the above-mentioned concepts all focus primarily on experiential outcomes of mental story models; it has remained largely unclear how the mental story model construction itself becomes a pleasurable experience instead of a strenuous one. Motivational psychology, however, offers a general explanation for the co-occurrence of effort and enjoyment in activity engagement: *flow* (Csikszentmihalyi, 1975). Flow is defined as an intrinsically enjoyable state of complete engagement with an activity that occurs as a function of perceived balance between one's skills and the activity's challenge level. Accordingly, the *flow channel model* (Csikszentmihalyi, 1975), which has found substantial empirical support (see Fong, Zaleski, & Leach, 2015, for an overview), ties flow to activities with a high, but not excessive challenge level. Flow experiences that emerge in those optimally challenging activity contexts are characterized by nine experiential phenomena, called *flow components*: (1) merging of action and awareness, (2) heightened focus of attention, (3) loss of self-awareness, (4) altered sense of time, (5) feeling of competence, (6) perception of coherent demands, (7) clarity of goals, (8) unambiguous understanding of activity feedback, and (9) intrinsic enjoyment (Csikszentmihalyi, 1975; Jackson & Marsh, 1996). Taken together, these components account for a high degree of absorption, fluent processing, and enjoyment in engagement with a challenging task (Rheinberg, Vollmeyer, & Engeser, 2003).

Primarily, flow has been studied in physical and competitive activities such as sports or gaming. Recent flow research, however, has expanded to mental activities as well. Fiction reading, specifically, has been linked to flow repeatedly both in theoretical discourse (e.g., Buselle & Bilandzic, 2008, 2009; Green et al., 2004) and in empirical studies (Massimini, Csikszentmihalyi, & Delle Fave, 1988; McQuillian & Conde, 1996; Thissen, Menninghaus, & Schlotz, 2018). In this context, some of the fluency-related flow components require a reading-specific adaptation (Thissen, Menninghaus, & Schlotz, 2020). Given that in a mental activity like reading, goals are internally rather than externally defined and engagement is cognitive rather than physical, flow components (5) to (8) are best understood in terms of mental story model construction processes: If the reader is able to adapt, alter, and expand his or her mental story model by integrating new information from the text successfully, an experience of competence, coherence, and clarity emerges, cumulating in high processing fluency, and ultimately in flow. High processing fluency during a flow experience should, in turn, render the construction of a vivid, elaborate mental story model more likely, thereby laying the groundwork for other narrative-driven aspects of a pleasurable reading experience. This way, flow may serve as the most basic mechanism underlying reading pleasure and play a mediating role between the actual activity of constructing a mental story model and potential experiential outcomes such as narrative transportation. In regard to suspense, identification, and cognitive involvement, preliminary evidence for such a mediation effect has already been found (Thissen, Menninghaus, & Schlotz, 2020). Therefore, integrating the flow concept into a theoretical framework of reading could advance the capability of reading research to understand, predict, and promote the occurrence of positive reading experiences.

The methods most commonly used in reading research, such as having readers think aloud (e.g., Miall & Kuiken, 1999) or give retrospective self-reports through interviews (e.g., Ross, 1999) or in questionnaires (e.g., Buselle & Bilandzic, 2009), can, however, only provide limited insight into flow: They either interrupt the reading process itself or merely focus on subsequent evaluations of the reading experience. To overcome these limitations, such methods should be combined with psychophysiological measures that are independent of self-awareness, memory effects, and self-report biases such as social desirability (Potter & Bolls, 2012). Psychophysiological measures seem well suited for reading research, all the more so as general methodological difficulties of psychophysiology such as distorting influences of physical effort or interference between measurement acquisition and activity engagement play only a minor role in this context.

To date, however, psychophysiological measures have scarcely been applied in reading research. To start with, their successful application requires a theoretical link between a physiological signal and a psychological state as well as a rigid experimental design to control for variability in the signal caused by sources unrelated to this state (Cacioppo, Tassinary, & Berntson, 2007). The critical degree of vagueness and overlap between the established reading concepts (Buselle & Bilandzic, 2009) has, however, rendered both theoretical links to psychophysiology and experimental manipulations problematic (Willems & Jacobs, 2016). For instance, in one of the few psychophysiological studies on reading experiences published so far, Sukalla, Bilandzic, Bolls, and Busselle (2015) tested the validity of a self-report scale for narrative engagement in terms of psychophysiological correlates. Yet, two of the four subdimensions of the scale were not investigated, as a viable experimental manipulation approach and theoretical associations with physiological signals were unclear for them. Building on the flow channel model as well as on psychophysiological findings, the present study was aimed at demonstrating that flow states can, in contrast, be successfully studied in readers by combining self-reports and psychophysiological measures.

To establish a rigid experimental design, flow researchers frequently resort to the flow channel model and accordingly manipulate an activity's challenge level (Moller, Meier, & Wall, 2010). The most common experimental paradigm involves a flow condition, in which demands match participants' skills, as well as an overload control condition with excessive demands and a boredom control conditions with minimal demands. Three strategies are commonly used for matching demands in the flow condition: the creation of an intermediate demand level (e.g., Rheinberg et al., 2003), a continuous adaptation of demands to the participant's performance (e.g., Keller & Blomann, 2008), and an assignment to a certain demand level according to the participant's pre-assessed skill level (e.g., Moller, Csikszentmihalyi, Nakamura, & Deci, 2007).

In reading contexts, however, dynamically adapting a text to the reader seems hardly feasible. Similarly, pre-assessing reader skills in a manner that is precise enough to assign readers to matching texts is not only difficult to do, but also falls short of acknowledging factors other than reader skills that influence whether readers perceive a text as optimally matching for themselves or not. To experience flow during reading, the complex interplay of content, stylistic features, and composition that forms the narrative has to optimally match the many reader variables that shape the reader response, such as cognitive skills, interest, familiarity, and personal preferences. Hence, a more differentiated consideration of optimal challenge is required: Challenge in the context of reading rather refers to felt stimulation and depends on various factors other than demands and skills only.

In light of these considerations, we opted for pre-selecting readers with regard to their previous self-reported flow experiences with a certain narrative. The underlying rationale was: When these readers are presented with another excerpt from the very narrative that had previously proven to be optimally stimulating for them, the chance of experiencing flow again should be relatively high. Because cognitive challenge constitutes one of the factors that determine the narrative's overall stimulation level, text versions of it with suboptimal challenge levels could then serve as control conditions with a diminished chance for flow as compared to the original. One potential way to operationalize cognitive challenge for this purpose is to focus on stylistic text demands only while keeping the content constant and thus the narrative itself comparable. The linguistic concept of *readability* affords a number of indices that quantify text demands with regard to the text's vocabulary and syntactic complexity. Readability is defined as "the ease of understanding or comprehension due to the style of writing" (Klare, 1963, p. 3) and can be approximated through text features such as the number of words per sentence or the number of syllables per word. Thus, a reasonable approach to implement control and flow conditions in a reading experiment, is to present three text versions (with low, intermediate, or high readability) of a narrative that has proven to be generally flow conducive for the reader sample at hand. Notably, this approach differs from the experimental paradigms in general flow research in that the likelihood for flow in the control conditions could still be relatively high due to content-related stimulation and readers' individual capabilities and dispositions. However, since readability holds great advantages over other text demand factors in terms of measurability, we decided to test whether and in how far this approach is still useful.

To formulate testable psychophysiological hypotheses for flow during reading, we focused on the theoretical link between activation in the parasympathetic nervous system (PSNS) and flow states during mental activities. The PSNS is the branch of the autonomic nervous system that is active during resting states and inner relaxation. The reciprocal branch, the sympathetic nervous system (SNS), is active during quick mobilizations of energy and heightened arousal (Cacioppo et al., 2007). Whereas the SNS responds to high levels of cognitive challenge and stress (Callister, Suwarno, & Seals, 1992), fluent processing in case of optimal mental stimulation is likely to be facilitated under PSNS dominance. Specifically, PSNS activation reflects the allocation of mental resources to the cognitive processing of surrounding stimuli (Potter & Bolls, 2012). Notably, this also holds for the cognitive processing of media stimuli (Wise, Bolls, Myers, & Sternadori, 2009). More efficient energy exchange (Grossman & Taylor, 2007), better information encoding (Park & Thayer, 2014), sustained attention (Luque-Casado, Perales, Cárdenas, & Sanabria, 2016), heightened focus (Wu & Lo, 2008), successful emotion regulation (Park & Thayer, 2014), and social cognition (Porges, 2011) have all been linked to PSNS dominance. Since these cognitive processes also play a role in constructing mental story models, PSNS dominance might be associated with their particularly fluent construction. Moreover, PSNS dominance is the psychophysiological equivalent of the heightened feelings of relaxation that are characteristic for positive reading experiences (Clark & Rumboldt, 2006; Nell, 1988). Importantly, emotional reader responses that might activate the SNS (Potter & Bolls, 2012) are temporally limited to specific parts of the story. Therefore, PSNS dominance should outweigh temporary SNS responses to the text when the psychophysiological signal is aggregated over the course of the reading phase.

To assess PSNS activity during reading, we employed cardiovascular measures that indicate cardiac vagal tone. The vagus nerve represents the most important parasympathetic connection between the heart and the brain. As illustrated in the *neurovisceral integration model* (Thayer, Hansen, Saus-Rose, & Johnsen, 2009; Thayer & Lane, 2009), high vagal tone reflects PSNS dominance and is associated both with fluent cognitive processing in prefrontal brain areas and with a distinct cardiovascular activation pattern. This pattern is characterized by a low heart rate (HR) and a high heart rate variability (HRV). The HR refers to the number of heart beats per minute (bpm), informs about both PSNS and SNS input, and is obtained by extrapolating intervals between adjacent positive deflections (so-called R spikes) in an electrocardiogram (ECG). The HRV, on the other hand, reflects the temporal variability between heart beats, provides more detailed information on PSNS activity only, and can be obtained computing the root mean square of successive differences (RMSSD) in the length of intervals between R spikes in an ECG (Malik et al., 1996). For further information on the measurement, interpretation, and use of these measures, please see Cacioppo et al. (2007) and Gramann and Schandry (2009) for HR, as well as Laborde, Mosely, and Thayer (2017), Malik et al. (1996), and Shaffer and Ginsberg (2017) for HRV-RMSSD.

To date, flow research involving cardiovascular measures has produced mixed results (see Knierim, Rissler, Dorner, Maedche, & Weinhardt, 2018, for an overview). Whereas some evidence points to SNS dominance during flow (Bian et al., 2016; De Manzano, Theorell, Harmat, & Ullén, 2010; Gaggioli, Cipresso, Serino, & Riva, 2013; Keller, Bless, Blomann, & Kleinböhl, 2011), other studies have identified heightened PSNS activation during flow in the form of a decreased HR (Drachen, Nacke, Yannakakis, & Pedersen, 2010) and increased HRV (Léger, Davis, Cronan, & Perret, 2014; Peifer, Schächinger, Engeser, & Antoni, 2015; Tozman, Magdas, MacDougall, & Vollmeyer, 2015). However, these studies have investigated mostly physical activities of widely divergent kind. Therefore, it is not clear which of these findings, if any, might be informative for reading research.

Against this background, we opted to take the known associations between PSNS dominance and fluent cognitive processing as well as felt relaxation as the starting point for our study. To test whether PSNS dominance underlies the fluent, seemingly effortless construction of mental story models that is accompanied by a flow experience during reading, we measured PSNS-driven vagal tone in the ECG signal both prior to and during reading. This way, we could not only test whether or not PSNS dominance is associated with flow during reading at all, but also in which specific form: as a person-dependent variable that moderates the occurrence of flow during reading in interaction with the text, or as a direct indicator for the occurrence of flow that changes in response to readers' flow experiences.

In case PSNS dominance represents a moderating variable for the occurrence of flow during reading, it should be interpreted as a determining factor on part of the reader that interacts with textual factors in creating an optimal stimulation level for the reader. Based on what is known about the cognitive and experiential consequences of PSNS dominance, readers with high cardiac vagal tone *prior to* reading (i.e., PSNS dominance), should be more prone to subsequently experiencing flow during reading, specifically when presented with a cognitively challenging text: Their PSNS dominance should allow them to optimally approach the text by fluently processing it and remaining relaxed. Therefore, these readers should also be more likely to experience the construction of the mental story model as optimally stimulating rather than excessively demanding. Accordingly, our first hypothesis was that self-reported flow experiences during reading can be predicted by an interaction between readers' cardiac vagal tone prior to reading and the text's cognitive challenge level, as operationalized by readability: The lower the text's readability, the stronger the positive association between flow and high cardiac vagal tone prior to reading (i.e., low HR as well as high RMSSD values) should turn out to be.

In case PSNS dominance rather represents an indicator for flow during reading, it would be a psychophysiological response to and effect of experiencing flow during reading. In this case, readers with high cardiac vagal tone *during* reading should generally be more likely to report flow experiences. Prompted by the subjective effortlessness and heightened processing fluency in constructing the mental story model under optimally stimulating reading conditions, the cardiovascular activation pattern of those readers who experience flow would change toward PSNS dominance. Hence, high cardiac vagal tone (i.e., PSNS dominance) as measured during reading could also differentiate readers who experience flow from those who do not. Accordingly, our second hypothesis was that self-reported flow experiences during reading can be predicted by readers' cardiac vagal tone during reading: Controlling for baseline, their PSNS activity should go up (i.e., HR should decelerate and RMSSD values should increase) in association with their flow experiences during reading across all reading conditions.

Methods

Participants

A total of 94 readers participated in the experiment. All participants were pre-selected based on their reading motivation and self-reported flow in a previous online study that involved reading a chapter of Homer's *Odyssey* (Thissen et al., 2020). In the pre-study, these participants had expressively indicated that they were motivated to read another *Odyssey* chapter in a follow-up experiment. In addition, their individual flow scores for reading the *Odyssey* chapter had scored above the response scale's midpoint on the flow measure. We surmised that these particular readers, when presented with a new *Odyssey* chapter in our experiment, would be likely to again experience an optimal stimulation level and thereby flow during reading. This assumption was based on findings regarding the stability of both reading motivation (Clark & Rumbold, 2006) and reader skills in adults (Schneider, Schlagmüller, & Ennemoser, 2017). Thus, we intentionally pre-selected participants who were in general likely to experience flow during the reading phase of our experiment.

The final sample size for the experiment was in the end reduced to $N = 84$ because questionnaire data from one participant were lost due to a technical problem and cardiovascular data from seven participants could not be edited due to trigger malfunctions. Additionally, two participants had cardiac pacemakers and were therefore excluded from the analysis. The final sample covered an age range from 19 to 73 years ($M = 35$; $SD = 16$), with the majority being female (57%; $n = 48$) and a considerable percentage holding graduate degrees (49%, $n = 41$). Our participants scored relatively high in reading self-efficacy ($M = 5.59$; $SD = 0.89$) as well as on reader skills such as reading accuracy ($M = 93.85$; $SD = 5.80$), reading speed ($M = 29.55$; $SD = 9.22$), and reading comprehension ($M = 55.36$; $SD = 17.23$), suggesting that they are avid readers. Participants were randomly assigned to one of three experimental conditions in which the low, intermediate, and high readability versions of the text were read, respectively. This randomization was successful in that the subsamples ($n = 29$; $n = 31$; $n = 24$) did not differ significantly across relevant characteristics such as demographics, reader variables, reader traits, and reader skills (see Supplemental Material, Table S1).

Design and Procedure

The study was conducted in a research laboratory that was designed to resemble a living room. Each participant completed the experiment individually under the surveillance of a research assistant. Upon arrival in the laboratory, the participant received a written description of the study, gave his or her informed consent, and was acquainted with the ECG equipment. Seated in a reading armchair, the participant filled out a questionnaire regarding reader traits and skills that was presented via LimeSurvey software (Schmitz, 2012) on a tablet computer.

Subsequently, the participant was prepared for the cardiovascular measurement. After the research assistant visually inspected the ECG signal, the participant was instructed to sit still and relax for 10 minutes. Then the participant was given a bookrest on which a book containing only the *Odyssey* chapter to be read was fixated. To prevent distractions, the research assistant left the room until the participant rang a bell and pushed a trigger to indicate that he or she had finished reading. After reading, the participant filled out a questionnaire in regard to the reading experience and once again was asked to sit still for a 10-min recovery phase. The participant was eventually debriefed and rewarded with 30 €. For a schematic representation of this procedure, please see Supplemental Material, Figure S1.

Reading Material

Each participant read one of three versions of a chapter of Homer's *Odyssey*, the ancient Greek story of Ulysses's eponymous wandering and adventures on his way home from the Trojan War. In this self-contained episode, Ulysses and his companions get trapped in the lair of a cyclops, a one-eyed, man-eating giant, and must rely on Ulysses's wits to save their lives. This storyline was the same for all text versions. Accordingly, textual demands dependent on narrative content and narrative structure were kept constant. At the same time, textual demands dependent on writing style varied across the conditions. To obtain three sufficiently distinct levels of stylistic text demand, we presented: (1) an older prose translation from 1958 by Wolfgang Schadewaldt as the most demanding text version; (2) a more recent prose translation from 2010 by Karl Ferdinand Lempp as the intermediate text version; and (3) a stylistically further simplified variant of the translation by Lempp (2010) that we created with the help of literary scholars as the least demanding text version.

To approximate the differences in cognitive challenge levels the three text versions might pose to readers, we first tokenized the texts with the NLTK sentence tokenizer (Bird & Loper, 2004, July). Then, we measured their readability with the Python *readability* package by van Cranenburgh (https://github.com/andreasvc/readability). In this way, we calculated several standard readability indices for German such as the Flesch–Kincaid Grade Level and the Gunning fog index. These indices are based on textual surface characteristics, mainly sentence length (in words) and counts of long and complex words. The older prose version, for instance, was characterized by long sentences and the use of outdated and difficult vocabulary; consequently, its readability should be relatively low. Readability indices overall confirmed our expectations: Readability was indeed low for the older prose version, intermediate for the more recent prose version, and high for our self-produced simplified variant of the latter (see Supplemental Material, Table S2).

Self-Report Measures

Demographic data as well as reader variables including frequency of reading fictional narratives, general affinity for fiction reading, and interest in reading the *Odyssey* were assessed using single items. Furthermore, we assessed reader traits that might influence the reading experience: reading self-efficacy, as measured by four self-developed items (Thissen et al., 2020); aesthetic responsiveness, as measured by the 14-item Aesthetic Responsiveness Assessment (AReA; Schlotz et al., 2020); and proneness to boredom, as measured by the 8-item Short Boredom Proneness Scale (SBPS; Struk, Carriere, Cheyne, & Danckert, 2017). To measure reader skills, we presented an online adaptation of Schneider, Schlagmüller, and Ennemoser's (2017) Reading Speed and Comprehension Test (Lesegeschwindigkeits- und Verständnistest; LGVT). This speed test comprises a cloze test with three response options per deletion, from which to choose based on the textual context. The LGVT provides information about reading speed, comprehension, and accuracy in adolescent reader samples, yet it appears to be applicable to more advanced readers as well (Thissen et al., 2020).

Regarding their reading experience in the experiment in terms of flow, participants answered the 27-item Fiction Reading Flow Scale (FRFS; Thissen et al., 2020). This scale has been developed to measure flow states specifically in the context of fiction reading, with instructions and items explicitly referring to the immediate reading experience. To further ensure its applicability for reading research, the theoretical adaptation required for fluency-related flow components in the reading context is reflected in the corresponding items. The FRFS had also been employed to measure readers' flow experiences in the pre-study. Additionally, rating items were used as a manipulation check to assess whether participants found the *Odyssey* chapter to be excessively or not very demanding to read.

Rating items were rated either on a 7-point Likert scale ranging from *not at all* to *very much* or with a binary response format. For the SBPS and FRFS, a 7-point Likert scale ranging from *strongly disagree* to *strongly agree* was employed. A 5-point Likert scale was used for both the reading self-efficacy items and the AReA, ranging from *not at all* to *very much* for the former and from *never* to *very often* for the latter. All scale scores were calculated by averaging responses. For further information about the item wordings and the scales employed, please see the Supplemental Material.

Cardiovascular Measures

ECG measurement was conducted according to established guidelines (Gramann & Schandry, 2009; Potter & Bolls, 2012) using a BioPlux amplifier (Plux, Portugal), which was connected via Bluetooth to a laptop computer running OpenSignals (r)evolution version 2018-03-27 (Plux, Portugal). To record the ECG, we used three pregelled 8-mm AG/AGCL ECG electrodes (H135SG, Covidien, Ireland) that were connected to the BioPlux amplifier's electrocardiography sensor (gain: 1.000; bandwidth: 0.5–100 Hz). The positive electrode was placed on the sternum, the negative electrode between the fourth and fifth rib on the left pectoralis major, and the grounding electrode above the rib at the end of the left rib cage. All data were sampled at a rate of 1,000 Hz and with a 16-bit resolution. Relaxation and reading phases were digitally marked using the BioPlux handheld switch trigger.

The ECG signal was postprocessed offline using Matlab's Fieldtrip (Oostenveld, Fries, Maris, & Schoffelen, 2011) and Biosig (Vidaurre, Sander, & Schlögl, 2011) toolboxes. First, data were extracted from the analog ECG waveforms with the appropriate transfer functions (Plux, Portugal) and edited using the trigger markers. To identify the RR intervals, we employed Biosig's nqrs-detect function, which decomposes the signal into subbands, downsamples it, and applies multiple beat-detection algorithms (Afonso, Tompkins, Nguyen, & Luo, 1999). As a correction for artifacts that may arise due to movement, electrical interference, or poor lead placement (Laborde et al., 2017), we applied square and quotient filters: The square filter filters out spikes in the signal which show RR intervals shorter than 300ms or longer than 2,000ms; the quotient filter filters out RR intervals that show more than a 20% change. This procedures separates incorrectly detected beats from heart beats with a sinus node origin (Piskorski & Guzik, 2005).

Data quality was subsequently confirmed by visually inspecting tachograms and Poincaré plots. To obtain the HR values, we transferred the filtered RR intervals to the time domain. To further obtain the HRV values, we reverted to Biosig's heartratevariability function, which calculates the RMSSD (Shaffer & Ginsberg, 2017). Both the HR and the RMSSD values were aggregated across the duration of the pre-reading relaxation baseline and across the duration of the reading phase for each participant.

Statistical Analysis

As a manipulation check, we examined group differences in terms of perceived demands across the conditions using Kruskal–Wallis tests and Bonferroni-adjusted Dunn's post hoc tests, given that Lilliefors tests had revealed nonnormality. We further explored whether flow experiences differed across conditions by conducting a one-way analysis of variance (ANOVA) and Bonferroni-adjusted pairwise *t*-tests as post hoc tests, since flow scores were normally distributed and showed equal variability in the three conditions.

We employed linear regression to test our two hypotheses, regressing flow scores on readers' HR and RMSSD values in separate models. In each model, we entered the experimental condition and its interaction with the cardiovascular indicator. To test hypothesis 1, we regressed flow scores on readers' baseline HR and RMSSD, respectively (Model A). To test hypothesis 2, we regressed flow scores on the change scores between the baseline and the reading HR and RMSSD, respectively (Model B).

To check the robustness of our results, we conducted sensitivity analyses. First, we repeated the regression models after excluding potentially influential outliers, defined as data points more than three standard deviations from the mean. Second, we adjusted the regression models for uncontrolled background or reader variables that might have influenced the results. This, however, was only the case for reader skills in terms of reading accuracy, for which our participants in the three conditions showed a marginally significant difference. All other background and reader variables assessed were equally distributed across conditions, implying that their potential influence on our results was already controlled for through successful experimental randomization.

Before conducting all regression analyses, we confirmed the basic assumptions of regression modeling by visually inspecting diagnostic plots for the linearity of associations, the normality of residuals, and potentially influential outliers. Subsequently, we tested the homogeneity of the error variance by means of Levene's tests. All statistical analyses were performed using R version 3.6.1 (R Core Team, 2016).

Results

Manipulation Check

Significant group differences for self-reported low and excessive demand ($\chi^2(2) = 10.65$, $p < .01$; $\chi^2(2) = 13.26$, $p < .01$) confirmed the efficacy of our experimental manipulation. On the one hand, participants in the high readability condition were more likely (*Mdn* = 5) to report finding text demands to be low compared to participants in the intermediate (*Mdn* = 2, $p < .05$) and in the low readability condition (*Mdn* = 2, $p < .05$). On the other hand, participants in the low readability condition were more likely (*Mdn* = 2) to report finding text demands excessive than those in the high readability condition (*Mdn* = 1, $p < .001$) and in the intermediate readability condition (*Mdn* = 1, $p < .001$). Thus, the respective demand levels of the three text versions were perceived as intended.

In regard to flow experiences during reading, we found a significant effect of the condition ($F[2, 81] = 3.17$, $p = .047$). Post hoc tests, however, did not confirm these group differences to be significant. Flow scores tended to be slightly lower only in the low readability condition, as compared to the high readability and intermediate readability conditions (see Table 1). As can be seen in Table 1, flow scores exceeded the midpoint of the response scale in all conditions. This observation indicates that, across readers and conditions, the reading experience in the experiment elicited flow.

Cardiovascular Activity and Flow During Reading

As can be seen in Table 2 and Table 3, respectively, hypothesis 1 was confirmed: In Model A, in which flow scores were regressed on cardiovascular baseline scores, the experimental condition—that is, the text's readability level—served as a moderator for the cardiovascular effect on flow experiences during reading. In regard to HR values (see Table 2), the interaction between baseline HR and experimental condition ($F[2, 78] = 4.99$, $p = .009$) as well as the main effects of baseline HR ($F[1, 78] = 7.90$, $p = .006$) and of experimental condition ($F[2, 78] = 3.76$, $p = .028$) were significant. Post hoc tests showed for both the intermediate readability condition ($F[1, 78] = 4.45$, $p = .038$) and for the low readability condition ($F[1, 78] = 12.77$, $p < .001$) that the regression slopes differed significantly from zero (see Figure 1).Regarding RMSSD values (see Table 3), the interaction between baseline RMSSD and experimental condition ($F[2, 78] = 3.71$, $p = .029$) as well as the main effect of experimental condition ($F[2,78] = 3.42$, $p = .038$) were significant, whereas the main effect of baseline RMSSD ($F[1, 78] = 1.68$, $p = .198$) was not. Post hoc tests showed that the regression slope was significantly different from zero ($F[2, 78] = 7.63$, $p = .007$) only in the low readability condition (see Figure 2). Thus, the interaction effect was stronger with regard to HR, but was consistent over both cardiovascular indicators: Readers who showed high cardiac vagal tone prior to reading—as reflected in relatively high HR and low RMSSD values—had a higher chance to enter a flow state when the text was written in a stylistically challenging way as compared to readers with low cardiac vagal tone prior to reading.On the contrary, no evidence was obtained for hypothesis 2, as can be seen in terms of Model B in Table 2 for the regression models involving HR values, and in Table 3 for the regression models involving RMSSD as the cardiovascular indicator, respectively. These models, in which flow scores were regressed on cardiovascular change scores,

TABLE 1
Summary of Correlations, Group Means, and Standard Deviations for Cardiovascular Measures During the Baseline and Reading Phases (Aggregated Within Phase) and for Self-Reported Flow Experience During Reading in the Three Experimental Conditions (High, Intermediate, and Low Readability)

	M	*SD*	1	2	3	4	5
High readability							
Baseline							
1. HR	71.93	10.14	–**	−.50***	.92***	−.37***	.16***
2. HRV-RMSSD	45.92	25.71		–**	−.45***	.91***	−.14***
Reading							
3. HR	71.37	9.35			–*	−.39***	.16***
4. HRV-RMSSD	45.31	23.43				–	−.13 -.*
5. Flow	5.54	0.73					–*
Intermediate readability							
Baseline							
1. HR	71.56	10.92	–**	−.59***	.96***	−.63***	−.42***
2. HRV-RMSSD	41.87	26.73		–**	−.54***	.95***	.20***
Reading							
3. HR	70.83	10.70			–*	−.59***	−.42***
4. HRV-RMSSD	40.23	24.56				–	.23***
5. Flow	5.54	0.68					–*
Low readability							
Baseline							
1. HR	74.71	10.94	–**	−.49***	.96***	−.68***	−.55***
2. HRV-RMSSD	38.94	17.77		–**	−.40***	.66***	.45***
Reading							
3. HR	76.33	10.96			–**	−.70***	−.56***
4. HRV-RMSSD	32.92	16.23				–	.56***
5. Flow	5.05	0.99					–

Note. HR = heart rate; HRV= heart rate variability; RMSSD = root mean square of successive differences in the HRV. * $p < .05$, ** $p < .01$, *** $p < .001$.

did not show any significant effects; the same holds for the corresponding overall tests of interaction and main effects.

For all regression models, excluding outliers from the analyses did not substantially alter the results. In case of the models involving RMSSD as the cardiovascular indicator, however, the interaction effect turned out to be only marginally significant. Adjusting for reader skills in terms of reading accuracy did not affect any of the results, implying that reading accuracy did not confound the observed effects of the text's readability level on the reader's flow experience (see Supplemental Material, Tables S3 to S6, for details).

Discussion

To advance the understanding of flow experiences during fiction reading, we conducted an experiment that investigated the interplay of cardiovascular activity and readers' self-reported flow under reading conditions with varying text demands. Whereas cardiovascular activity is a physiological measure linked to cognitive text processing, flow is a psychological state linked to reading pleasure. Flow during reading is likely to be experienced whenever the construction of the mental story model becomes particularly fluent and subjectively effortless due to a perceived optimal stimulation level. In our experiment, we presented

TABLE 2

Summary of Regression Analyses for the Mean Heart Rate (in bpm) Predicting Readers' Self-Reported Flow Experiences by Experimental Condition (High, Intermediate, and Low Readability); Reference Group Is High Readability

	Model A				Model B			
	B	*SE*	β	*p*	*B*	*SE*	β	*p*
Intercept	5.542	0.14	.00	< **.001**	5.532	0.15	.00	< **.001**
Intermediate readability	−0.028	0.19	−.02	.884	0.009	0.21	.01	.968
Low readability	−0.383	0.20	−.21	.065	−0.465	0.24	−.26	.058
Baseline HR	0.011	0.14	.15	.416				
Intermediate readability × baseline HR	−0.037	0.18	−.30	**.047**				
Low readability × baseline HR	−0.061	0.20	−.44	**.003**				
HR change					−0.005	0.04	−.02	.888
Intermediate readability × HR change					0.005	0.06	.01	.940
Low readability × HR change					−0.003	0.07	−.01	.965
R^2	.25				.07			

Note. HR = heart rate. The HR was centered at the grand mean of each phase (72.6 bpm for baseline values and 0.002 bpm for change scores). Model A uses participants' baseline HR as the cardiovascular predictor, whereas Model B uses the HR change score—that is, participants' average baseline HR subtracted from their average HR during reading—as the cardiovascular predictor.

participants with a narrative that was likely to be optimally stimulating and therefore flow inducing for them. We manipulated the text's stimulation level, however, by presenting the narrative in three versions of high, intermediate, or low readability, and hence of differing degrees of cognitive challenge. Cardiovascular activity was measured both prior to and during reading, and subjectively experienced flow was measured with a reading-specific self-report scale immediately after reading.

The basic assumption of our experimental design, that is, that readability can be used to operationalize and manipulate the text's demand level, was confirmed:

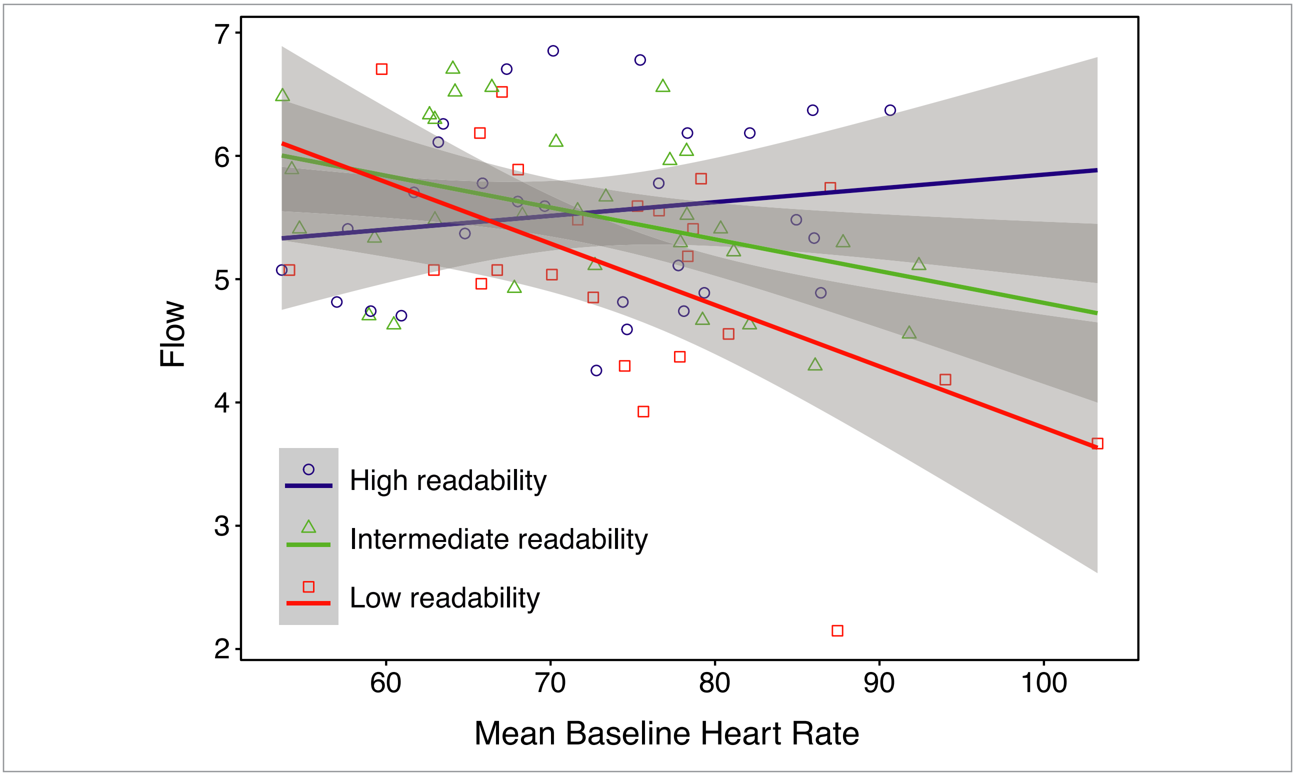
TABLE 3

Summary of Regression Analyses for the Root Mean Square of Successive Differences in the HRV (in ms) Predicting Readers' Self-Reported Flow Experiences by Experimental Condition (High, Intermediate, and Low Readability); Reference Group Is High Readability

	Model A				Model B			
	B	*SE*	β	*p*	*B*	*SE*	β	*p*
Intercept	5.549	0.14	.00	< **.001**	5.538	0.15	.00	< **.001**
Intermediate readability	−0.005	0.20	−.00	.979	0.011	0.21	.01	.961
Low readability	−0.408	0.22	−.23	.061	−0.451	0.23	−.25	.058
Baseline RMSSD	−0.004	0.01	−.12	.477				
Intermediate readability × baseline RMSSD	0.009	0.01	.18	.237				
Low readability × baseline RMSSD	0.029	0.01	.34	**.008**				
RMSSD change					0.005	0.02	.06	.751
Intermediate readability × RMSSD change					−0.000	0.02	−.00	.993
Low readability × RMSSD change					0.001	0.02	.01	.966
R^2	.17				.08			

Note. RMSSD = root mean square of successive differences. The RMSSD was centered at the grand mean (42.4 ms for baseline values and -2.5 ms for change scores). Model A uses participants' baseline RMSSD as the cardiovascular predictor, whereas Model B uses the RMSSD change score—that is, participants' baseline RMSSD subtracted from their RMSSD during reading—as the cardiovascular predictor.

FIGURE 1
Associations Between Readers' Self-Reported Flow Experiences in Each Experimental Condition (High, Intermediate, and Low Readability) and Mean Heart Rate (in bpm) during the Baseline Phase. Confidence Intervals are Represented by Gray-Shaded Areas



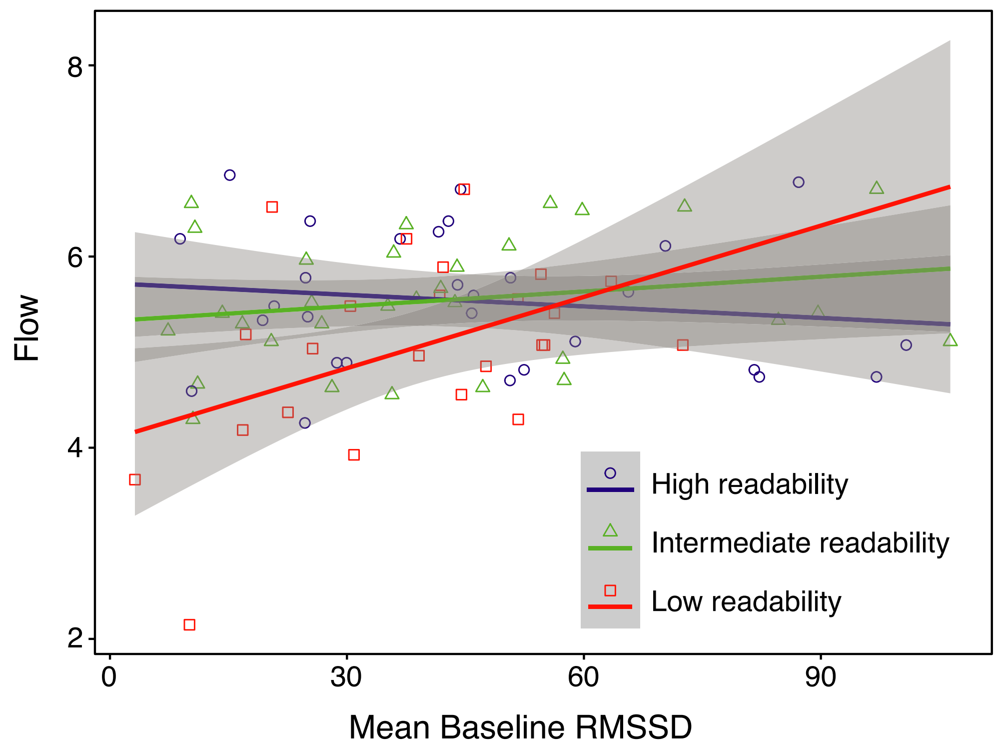
Note. The color figure can be viewed in the online version of this article at http://ila.onlinelibrary.wiley.com.

Participants in the high readability condition perceived the text as rather simple to read, whereas participants in the low readability condition perceived the text as rather difficult. However, participants reportedly experienced flow across all three experimental conditions. This result, although at first glance surprising, is likely to reflect the influence of a variety of factors other than purely style-driven readability that may influence the reader's subjective evaluation of the reading situation as optimally stimulating and thereby flow inducing: individual differences in reader skills, reading motivation, interest, personal preferences, and responses to cognitive challenge, as well as content-related text demands. Taken together, all these factors apparently outweighed the expected adverse effect of suboptimal readability on flow experiences in the reading phase of our experiment.

In particular, motivation- and expertise-related factors most likely led to an increased potential for flow even under otherwise suboptimal reading conditions in our reader sample. High motivation is known to affect subjective demand evaluations in a way that favors the perception of optimal stimulation and thereby flow experiences (Engeser & Rheinberg, 2008; Rheinberg et al., 2003). Thus, motivational aspects of the experimental situation as well as our participants' high self-reported motivation to read another chapter of the *Odyssey* could have generally increased their chance of experiencing flow. Similarly, expertise might generally increase the chance of flow during reading, since expert readers are more equipped to optimally respond even to suboptimal reading conditions. For instance, McNamara and Kintsch (1996) found that low readability does not stop experienced readers from fluently processing the text and constructing an adequate mental model from it. Considering that our reader sample showed high reading self-efficacy and reader skills, they could have simply been able to overcome the suboptimal text demands.

Taken together, we are faced with a mixed picture of results in regard to our experimental design: On the one hand, the on-average relatively high flow scores in our experiment demonstrate that flow can be successfully induced and thus studied in readers under controlled laboratory conditions, which are particularly crucial for tests of psychophysiological hypotheses. On the other hand, the marginal differences we found in flow scores across experimental conditions imply that a thorough experimental manipulation of flow during reading cannot rely solely on varying the text's stylistic features and readability. Even though our readability manipulations might have simply not been strong enough to obtain significant text version dependent differences in flow, even

FIGURE 2
Associations Between Readers' Self-Reported Flow Experiences in Each Experimental Condition (High, Intermediate, and Low Readability) and RMSSD (in ms) Extracted Over the Baseline Phase. Confidence Intervals are Represented by Gray-Shaded Areas



Note. The color figure can be viewed in the online version of this article at http://ila.onlinelibrary.wiley.com.

stronger ones could impair the ecological validity of the text stimuli in a way that renders drawing valid conclusions about reading experiences impossible. For this reason, future studies should explore additional approaches to manipulating the text's stimulation level, for instance also in regard to its narrative content and narrative structure. However, given the many difficulties of such text manipulations, matching text and reader might in fact be the more viable approach to future experimental reading research on flow.

To date, this particular approach seemed hardly feasible in reading research due to the plethora of factors to be considered and the methodological problems in assessing and manipulating them. For instance, Shahian, Pishghadam, and Khajavy (2017) implemented a quasi-experimental design by matching texts to readers based on their familiarity with the text's topic. These differences in thematic familiarity were expected to result in varying stimulation levels and thus varying flow potential across conditions. This design, however, led to hardly comparable reading situations in the different conditions, since participants read different texts and not just different versions of the same text. Our results point to a new way that may help overcome such methodological problems in matching text and reader: Taking a text demand factor like readability, that can be relatively easily manipulated and varied across conditions, and a psychophysiological factor like readers' cardiovascular activity, that can be easily measured, as key factors for matching text and reader.

This new matching approach can be derived from our results concerning the first hypothesis, which assumed that readers' flow experiences arise from an interplay between their inner state prior to reading and the text's cognitive challenge level. Specifically, our reading experiment revealed significant associations between cardiovascular activity and subjective flow experiences: An interaction of cardiac vagal tone before reading—a psychophysiological factor on part of the reader—and readability—a demand factor on part of the text—determined the likelihood of a flow experience during reading. Low HR and high RMSSD values prior to reading, both reflective of high cardiac vagal tone, supported subsequent flow experiences during reading when the text posed a considerable cognitive challenge by virtue of its intermediate-to-low readability level. In contrast, in the high readability condition of the experiment, in which participants were presented with a text version that was written in a very simple style of low cognitive challenge to the reader, we found no significant associations between cardiac vagal tone and flow during reading.

This interaction effect is in line with both the flow channel model (Csikszentmihalyi, 1975) and the neurovisceral integration model (Thayer et al., 2009; Thayer & Lane, 2009). The former postulates that flow emerges from a match between the individual's disposition and the respective activity, allowing for an optimal response to challenge. The latter postulates that PSNS-driven high cardiac vagal tone enables individuals to respond to certain cognitive challenges more fluently. Since the construction of a mental story model becomes cognitively more challenging the lower the text's readability level is, the reader's cardiac vagal tone before reading can be seen as an indicator for his or her preparedness to still optimally respond to this challenge such that a flow experience can arise. Therefore, the text's style-driven demand level can be interpreted as a determinant for flow, provided, however, that the reader's inner state before reading, specifically his or her cardiac vagal tone, is taken into account as a moderating factor.

The impact of readers' inner state on their text processing has already been shown in terms of mood-driven effects on text comprehension (Bohn-Gettler & Rapp, 2014; Mills, Wu, & D'Mello, 2019) and narrative transportation (Green, Chatham, & Sestir, 2012). Even though cardiac vagal tone reflects a certain arousal level rather than an affective state, these earlier findings support the idea that implicit factors within the reader have a bearing on his or her reading experience. Since high cardiac vagal tone indicates an inner state of relaxation associated with fluent cognitive processing, readers in this state should be more likely to optimally respond also to high cognitive challenges, not only by calmly approaching them but also by better performing the necessary cognitive processes to meet them. In a mental activity like fiction reading, cardiac vagal tone seems to support the subjective experience of relatively high demands as optimally stimulating and hence as flow inducing.

Considering that we measured cardiac vagal tone before reading, this mechanism can be interpreted causally; that is, the reader's inner state before reading determines how the subsequent reading situation and its challenge level is experienced. Whether high cardiac vagal tone should be interpreted as a situational or a dispositional factor, however, remains to be tested. On the one hand, cardiac vagal tone during resting states is known to be a relatively stable individual characteristic (Thayer & Lane, 2009) that can influence cognitive performance on a general level (Park & Thayer, 2014). On the other hand, the cardiovascular data we obtained in the relaxation phase before reading represent only a brief state assessment that may well be more reflective of the experimental situation than of a trait-like disposition. To test whether high cardiac vagal tone could be a dispositional factor that indicates a person's general proneness to flow experiences during reading, future reading experiments should include long-term cardiovascular baseline measures.

Comparisons between different types of cognitive tasks have revealed that cardiac vagal tone is linked in particular to perceptual abilities and sustained attention (Luque-Casado et al., 2016; Luque-Casado, Zabala, Morales, Mateo-March, & Sanabria, 2013) . These cognitive skills seem especially relevant for basic text comprehension. Following this rationale, the way in which readers get into flow might best be understood in terms of mastering two different types of challenge. Basic text comprehension as dependent on successfully coping with the text's writing style is the first type of challenge. Our findings suggest that PSNS dominance prior to reading—as indicated by high cardiac tone—can positively affect the cognitive processes required to master it. The second type of challenge pertains to engagement with the narrative in regard to its plot, characters, and story world. Considering that participants in the high readability condition of our experiment reported as much flow as participants in the other conditions, but that their flow experiences emerged independent of cardiac vagal tone, mastering this type of challenge seems largely unaffected by PSNS dominance and cardiac vagal tone. If and which other psychophysiological factors may come into play in mastering this type of challenge during reading remains to be tested in future studies.

Contrary to the promising results we obtained when looking into psychophysiological measures as personal factors that moderate text effects on flow experiences during reading, we had to reject the second hypothesis, namely, that psychophysiology, in particular high cardiac vagal tone, might directly reflect the flow state in readers. The HR and RMSSD data we obtained suggest that our participants' cardiovascular activity was virtually the same during both the relaxation and the reading phase of our experiment. Moreover, we found no significant associations between self-reported flow during reading and changes in cardiac vagal tone: HR and RMSSD values—and hence cardiac vagal tone—during reading were no longer systematically linked to readers' flow experiences once individual differences in the inner state prior to reading were accounted for by controlling for baseline values. Consequently, according to our results, cardiac vagal tone cannot be taken as a direct indicator of flow during reading as it did not change in association with the reading experience or flow.

Still, it may be worthwhile to continue the search for an objective indicator of flow during reading by using a more fine-grained analysis of the temporal dynamics within the reading process and a combination of psychophysiological measures. As we aggregated psychophysiological measures over the whole reading phase and focused on cardiovascular activity only, the insight we could gain into the psychophysiology of optimal reading experiences was certainly limited. Moreover, given that our study involved a pre-selected, unrepresentative reader sample that covered a fairly wide age range and was predominantly made up of avid readers, as well as only a single narrative, more studies are called for to test the robustness and generalizability of our results.

Notwithstanding, our study provides first evidence for the potential of psychophysiological flow research in fiction reading. On the one hand, our results demonstrate that flow is a useful concept for reading researchers as it provides insight into the mental mechanism that underlie the pleasure taken in constructing mental story models during reading. Flow researchers, on the other hand, could further their understanding of what is universally characteristic of the flow experience by combining psychophysiological findings from the traditionally studied physical activities with those from mental activities like fiction reading. The interaction effect we found between cardiac vagal tone before and flow during reading suggests that parasympathetic dominance is an inner state that is favorable for the emergence of flow in challenging situations. Since flow experiences in challenging situations motivate engagement with learning opportunities, finding ways to support their emergence, both in fiction reading and beyond, constitutes an important research aim. Our study suggests that psychophysiology could be a helpful tool in achieving this aim. Still, our study is only the first step into a largely uncharted territory. Thus, building on the fundamental research presented in this paper, more application-oriented studies may follow suit that, for instance, look into the role of flow in educational reading settings and how teachers can promote their students flow experiences in a meaningful way.

NOTES

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REFERENCES

Afonso, V. X., Tompkins, W. J., Nguyen, T. Q., & Luo, S. (1999). ECG beat detection using filter banks. *IEEE Transactions on Biomedical Engineering*, *46*(2), 192–202. https://doi.org/10.1109/10.740882

Appel, M., & Richter, T. (2007). Persuasive effects of fictional narratives increase over time. *Media Psychology*, *10*(1), 113–134. https://doi.org/10.1080/15213260701301194

Bian, Y., Yang, C., Gao, F., Li, H., Zhou, S., Li, H., Sun, X., & Meng, X. (2016). A framework for physiological indicators of flow in VR games: Construction and preliminary evaluation. *Personal Ubiquitous Computing*, *20*(5), 821–832. https://doi.org/10.1007/s00779-016-0953-5

Bird, S., & Loper, E. (2004, July). *NLTK: The Natural Language Toolkit*. Paper presented at the Proceedings of the ACL Interactive Poster and Demonstration Sessions, Barcelona, Spain. https://www.aclweb.org/anthology/P04-3031

Bohn-Gettler, C. M., & Rapp, D. N. (2014). Emotion during reading and writing. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *Educational psychology handbook series. International handbook of emotions in education* (pp. 437–457). Routledge/Taylor & Francis Group.

Buselle, R., & Bilandzic, H. (2008). Fictionality and perceived realism in experiencing stories: A model of narrative comprehension and engagement. *Communication Theory*, *18*(2), 255–280. https://doi.org/10.1111/j.1468-2885.2008.00322.x

Buselle, R., & Bilandzic, H. (2009). Measuring narrative engagement. *Media Psychology*, *12*(4), 321–347. https://doi.org/10.1080/15213260903287259

Cacioppo, J. T., Tassinary, L. G., & Berntson, G. (2007). *Handbook of psychophysiology*. Cambridge University Press.

Callister, R., Suwarno, N. O., & Seals, D. R. (1992). Sympathetic activity is influenced by task difficulty and stress perception during mental challenge in humans. *The Journal of Physiology*, *454*(1), 373–387. https://doi.org/10.1113/jphysiol.1992.sp019269

Clark, C., & Rumbold, K. (2006). Reading for pleasure: A research overview. *National Literacy Trust*. Retrieved from https://literacytrust.org.uk/research-services/research-reports/reading-pleasure-research-overview/

Csikszentmihalyi, M. (1975). *Beyond boredom and anxiety: The experience of play in work and games*. Jossey-Bass.

De Manzano, Ö., Theorell, T., Harmat, L., & Ullén, F. (2010). The psychophysiology of flow during piano playing. *Emotion*, *10*(3), 301–310. https://doi.org/10.1037/a0018432

Drachen, A., Nacke, L. E., Yannakakis, G., & Pedersen, A. L. (2010). Correlation between heart rate, electrodermal activity, and player experience in first-person shooter games. In S.N. Spencer (Ed.), *Proceedings of the 5th ACM SIGGRAPH symposium on video games* (pp. 49–54). ACM.

Engeser, S., & Rheinberg, F. (2008). Flow, performance and moderators of challenge-skill balance. *Motivation and Emotion*, *32*(3), 158–172. https://doi.org/10.1007/s11031-008-9102-4

Fong, C. J., Zaleski, D. J., & Leach, J. K. (2015). The challenge-skill balance and antecedents of flow: A meta-analytic investigation. *The Journal of Positive Psychology*, *10*(5), 425–446. https://doi.org/10.1080/17439760.2014.967799

Gaggioli, A., Cipresso, P., Serino, S., & Riva, G. (2013). Psychophysiological correlates of flow during daily activities. *Annual Review of Cybertherapy and Telemedicine*, *191*, 65–69. https://doi.org/10.3233/978-1-61499-282-0-65

Gerrig, R. J. (1993). *Experiencing narrative worlds: On the psychological activity of reading*. Yale University Press.

Gramann, K., & Schandry, R. (2009). *Psychophysiology*. Beltz.

Green, M. C., Brock, T. C., & Kaufman, G. E. (2004). Understanding media enjoyment: The role of transportation into narrative worlds. *Communication Theory*, *14*(4), 311–327. https://doi.org/10.1111/j.1468-2885.2004.tb00317.x

Green, M. C., Chatham, C., & Sestir, M. A. (2012). Emotion and transportation into fact and fiction. *Scientific Study of Literature*, *2*(1), 37–59. https://doi.org/10.1075/ssol.2.1.03gre

Green, M. C., Garst, J., Brock, T. C., & Chung, S. (2006). Fact versus fiction labeling: Persuasion parity despite heightened scrutiny of fact. *Media Psychology*, *8*(3), 267–285. https://doi.org/10.1207/s1532785xmep0803_4

Grossman, P., & Taylor, E. W. (2007). Toward understanding respiratory sinus arrhythmia: Relations to cardiac vagal tone, evolution, and biobehavioral functions. *Biological Psychology*, *74*(2), 263–285. https://doi.org/10.1016/j.biopsycho.2005.11.014

Jackson, S. A., & Marsh, H. W. (1996). Development and validation of a scale to measure optimal experience: The flow state scale. *Journal of Sport & Exercise Psychology*, *18*(1), 17–35. https://doi.org/10.1123/jsep.18.1.17

Keller, J., Bless, H., Blomann, F., & Kleinböhl, D. (2011). Physiological aspects of flow experiences: Skills-demand-compatibility effects on heart rate variability and salivary cortisol. *Journal of Experimental Social Psychology*, *47*(4), 849–852. https://doi.org/10.1016/j.jesp.2011.02.004

Keller, J., & Blomann, F. (2008). Locus of control and the flow experience: An experimental analysis. *European Journal of Personality*, *22*(7), 589–607. https://doi.org/10.1002/per.692

Klare, G. R. (1963). *Measurement of readability*. University of Iowa Press.

Knierim, M. T., Rissler, R., Dorner, V., Maedche, A., & Weinhardt, C. (2018). The psychophysiology of flow: A systematic review of peripheral nervous system features. In F. Davis, R. Riedl, J. vom Brocke, P.-M. Léger, & A. Randolph (Eds.), *Information systems and neuroscience* (pp. 109–120). Springer.

Kuijpers, M. M. (2017). Towards a new understanding of absorbing reading experiences. In F. Hakemulder, M. M. Kuijpers, E. S. H. Tan, K. Balint, & M. M. Doicaru (Eds.), *Narrative absoption*. John Benjamins Publishing.

Laborde, S., Mosley, E., & Thayer, J. F. (2017). Heart rate variability and cardiac vagal tone in psychophysiological research: Recommendations for experiment planning, data analysis, and data reporting. *Frontiers in Psychology*, *8*(213), 1–18. https://doi.org/10.3389/fpsyg.2017.00213

Léger, P.-M., Davis, F. D., Cronan, T. P., & Perret, J. (2014). Neurophysiological correlates of cognitive absorption in an enactive training context. *Computers in Human Behavior*, *34*, 273–283. https://doi.org/10.1016/j.chb.2014.02.011

Lempp, K. F. (2010). *Odyssee [Odyssey]*. Insel Verlag.

Luque-Casado, A., Perales, J. C., Cárdenas, D., & Sanabria, D. (2016). Heart rate variability and cognitive processing: The autonomic response to task demands. *Biological Psychology*, *113*, 83–90. https://doi.org/10.1371/journal.pone.0056935

Luque-Casado, A., Zabala, M., Morales, E., Mateo-March, M., & Sanabria, D. (2013). Cognitive performance and heart rate variability: The influence of fitness level. *PloS One*, *8*(2), 1–9. https://doi.org/10.1371/journal.pone.0056935

Malik, M., Bigger, J. T., Camm, A. J., Kleiger, R. E., Malliani, A., Mosse, A. J., & Schwartz, P. J. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *European Heart Journal*, *17*(3), 354–381. https://doi.org/10.1161/01.CIR.93.5.1043

Massimini, F., Csikszentmihalyi, M., & Delle Fave, A. (1988). Flow and bicultural evolution. In M. Csikszentmihalyi & I. Csikszentmihalyi (Eds.), *Optimal experience: Psychological studies of flow in consciousness*. Cambridge University Press.

McNamara, D. S., & Kintsch, W. (1996). Learning from texts: Effects of prior knowledge and text coherence. *Discourse Processes*, *22*(3), 247–288. https://doi.org/10.1080/01638539609544975

McNamara, D. S., & Magliano, J. (2009). Toward a comprehensive model of comprehension. *Psychology of Learning and Motivation*, *51*, 297–384. https://doi.org/10.1016/S0079-7421(09)51009-2

McQuilian, J., & Conde, G. (1996). The conditions of flow in reading: Two studies of optimal experience. *Reading Psychology*, *17*(2), 109–135. https://doi.org/10.1080/0270271960170201

Miall, D. S., & Kuiken, D. (1999). What is literariness? Three components of literary reading. *Discourse Processes*, *28*(2), 121–138. https://doi.org/10.1080/01638539909545076

Mills, C., Wu, J., & D'Mello, S. (2019). Being sad is not always bad: The influence of affect on expository text comprehension. *Discourse Processes*, *56*(2), 99–116. https://doi.org/10.1080/0163853X.2017.1381059

Moller, A. C., Csikszentmihalyi, M., Nakamura, J., & Deci, E. L. (2007, February). *Developing an experimental induction of flow*. Paper presented at the Society for Personality and Social Psychology Conference, Memphis, TN.

Moller, A. C., Meier, B. P., & Wall, R. D. (2010). Developing an experimental induction of flow: Effortless action in the lab. In B. Bruya (Ed.), *Effortless attention: A new perspective in the cognitive science of attention action* (pp. 191–204). MIT Press.

Murray, J. (1997). *Hamlet on the Holodeck: The future of narrative in cyberspace*. The MIT Press.

Nell, V. (1988). The psychology of reading for pleasure : Needs and gratifications. *Reading Research Quarterly*, *23*(1), 6–50. https://doi.org/10.2307/747903

Oostenveld, R., Fries, P., Maris, E., & Schoffelen, J.-M. (2011). FieldTrip: Open source software for advanced analysis of MEG, EEG, and invasive electrophysiological data. *Computational Intelligence and Neuroscience*, *6*(1), 1–9. https://doi.org/10.1155/2011/156869

Park, G., & Thayer, J. F. (2014). From the heart to the mind: Cardiac vagal tone modulates top-down and bottom-up visual perception and attention to emotional stimuli. *Frontiers in Psychology*, *5*, 1–8. https://doi.org/10.3389/fpsyg.2014.00278

Peifer, C., Schächinger, H., Engeser, S., & Antoni, C. H. (2015). Cortisol effects on flow-experience. *Psychopharmacology*, *232*(6), 1165–1173. https://doi.org/10.1007/s00213-014-3753-5

Piskorski, J., & Guzik, P. (2005). Filtering poincare plots. *Computational Methods in Science and Technology*, *11*(1), 39–48. https://doi.org/10.12921/cmst.2005.11.01.39-48

Porges, S. W. (2011). *The polyvagal theory: Neurophysiological foundations of emotions, attachment, communication, and self-regulation (Norton series on interpersonal neurobiology)*. W.W. Norton & Company.

Potter, R. F., & Bolls, P. (2012). *Psychophysiological measurement and meaning: Cognitive and emotional processing of media*. Routledge.

RCoreTeam. (2016). *R: A language and environment for statistical computing [Computer software]*. R Foundation for Statistical Computing.

Rheinberg, F., Vollmeyer, R., & Engeser, S. (2003). Die Erfassung des Flow-Erlebens [Assessment of flow experiences]. In J. Stiensmeier-Pelster & F. Rheinberg (Eds.), *Diagnostik von Motivation und Selbstkonzept [Diagnosis of motivation and self-concept]* (pp. 261–279). Hogrefe.

Ross, C. S. (1999). Finding without seeking: The information encounter in the context of reading for pleasure. *Information Processing & Management*, *35*(6), 783–799. https://doi.org/10.1016/S0306-4573(99)00026-6

Schadewaldt, W. (1958). *Odysee [Odyssey]*. Rowohlt.

Schlotz, W., Wallot, S., Omigie, D., Masucci, M. D., Hoelzmann, S. C., & Vessel, E. A. (2020). The aesthetics responsiveness assessment (AReA): A screening tool to assess individual differences in responsiveness to art in English and German. *Psychology of Aesthetics, Creativity, and the Arts*, Advance online publication. https://doi.org/10.1037/aca0000348

Schmitz, C. (2012). *LimeSurvey: The free and open source survey software tool! [Computer software]*. LimeSurvey Developement Team.

Schneider, W., Schlagmüller, M., & Ennemoser, M. (2017). *LGVT 5–12+: Lesegeschwindigkeits- und Verständnistest für die Klassen 5–12 [LGVT 5–12+: Reading speed and text comprehension test for grades 5 to 12; Measurement instrument]*. Hogrefe.

Shaffer, F., & Ginsberg, J. P. (2017). An overview of heart rate variability metrics and norms. *Frontiers in Public Health*, *5*, 1–17. https://doi.org/10.3389/fpubh.2017.00258

Shahian, L., Pishghadam, R., & Khajavy, G.H. (2017). Flow and reading comprehension: Testing the mediating role of emotioncy. *Issues in Educational Research*, *27*(3), 527–549. Retrieved from http://www.iier.org.au/iier27/shahian.html

Struk, A. A., Carriere, J. S., Cheyne, J. A., & Danckert, J. (2017). A short boredom proneness scale: Development and psychometric properties. *Assessment*, *24*(3), 346–359. https://doi.org/10.1177/1073191115609996

Sukalla, F., Bilandzic, H., Bolls, P. D., & Busselle, R. W. (2015). Embodiment of narrative engagement. *Journal of Media Psychology*, *28*(4), 175–186. https://doi.org/10.1027/1864-1105/a000153

Thayer, J. F., Hansen, A. L., Saus-Rose, E., & Johnsen, B. H. (2009). Heart rate variability, prefrontal neural function, and cognitive performance: The neurovisceral integration perspective on self-regulation, adaptation, and health. *Annals of Behavioral Medicine*, *37*(2), 141–153. https://doi.org/10.1007/s12160-009-9101-z

Thayer, J. F., & Lane, R. D. (2009). Claude Bernard and the heart-brain connection: Further elaboration of a model of neurovisceral

integration. *Neuroscience & Biobehavioral Reviews*, *33*(2), 81–88. https://doi.org/10.1016/j.neubiorev.2008.08.004
Thissen, B. A. K., Menninghaus, W., & Schlotz, W. (2018). Measuring optimal reading experiences: The reading flow short scale. *Frontiers in Psychology*, *9*, 1–12. https://doi.org/10.3389/fpsyg.2018.02542
Thissen, B. A. K., Menninghaus, W., & Schlotz, W. (2020). The pleasures of reading fiction explained by flow, presence, identification, suspense, and cognitive involvement. *Psychology of Aesthetics, Creativity, and the Arts*, Advance online publication. https://doi.org/10.1037/aca0000367
Tozman, T., Magdas, E. S., MacDougall, H. G., & Vollmeyer, R. (2015). Understanding the psychophysiology of flow: A driving simulator experiment to investigate the relationship between flow and heart rate variability. *Computers in Human Behavior*, *52*, 408–418. https://doi.org/10.1016/j.chb.2015.06.023
Tucholsky, K. (1932, April 12). Momente beim Lesen [Moments during reading]. *Die Weltbühne [The World Stage]*, p. 573.
van Dijk, T. A., & Kintsch, W. (1983). *Strategies of discourse comprehension*. Academic Press.
Vidaurre, C., Sander, T. H., & Schlögl, A. (2011). BioSig: The free and open source software library for biomedical signal processing. *Computational Intelligence and Neuroscience*, *6*(1), 1–12. https://doi.org/10.1155/2011/935364
Willems, R. M., & Jacobs, A. M. (2016). Caring about Dostoyevsky: The untapped potential of studying literature. *Trends in Cognitive Sciences*, *20*(4), 243–245. https://doi.org/10.1016/j.tics.2015.12.009
Wise, K., Bolls, P., Myers, J., & Sternadori, M. (2009). When words collide online: How writing style and video intensity affect cognitive processing of online news. *Journal of Broadcasting & Electronic Media*, *53*(4), 532–546. https://doi.org/10.1080/08838150903333023
Wu, S.-D., & Lo, P.-C. (2008). Inward-attention meditation increases parasympathetic activity: A study based on heart rate variability. *Biomedical Research*, *29*(5), 245–250. https://doi.org/10.2220/biomedres.29.245
Zwaan, R. A., Langston, M. C., & Graesser, A. C. (1995). The construction of situation models in narrative comprehension: An event-indexing model. *Psychological Science*, *6*(5), 292–297. https://doi.org/10.1111/j.1467-9280.1995.tb00513.x
Zwaan, R. A., & Radvansky, G. (1998). Situation models in language comprehension and memory. *Psychological Bulletin*, *123*(2), 162–185. https://doi.org/10.1037/0033-2909.123.2.162

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Supplementary Material