Diaphragmatic breathing interfaces to promote relaxation in brief behavioral treatment for insomnia: A pilot study

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Abstract

Background: Brief behavioral treatment for insomnia is an effective short-term therapy focusing on stimulus control and sleep restriction to enhance sleep quality. As a crucial part of this therapy, diaphragmatic breathing is often recommended when patients fail to fall asleep within 30 minutes. With the rise of health applications and gamification, these tools are increasingly seen as effective ways to boost self-efficacy and user engagement; however, traditional games tend to increase attention, which can negatively impact sleep and contradicts the aim of sleep therapy. This study thus explored the potential for gamification techniques to promote relaxation without disrupting sleep processes.

Objective: The study developed four breathing guidance mechanisms, ranging from concrete to abstract: number countdown, zoom in/out, up/down, and color gradients. The objective was to explore the relationship between game mechanics, cognitive load, relaxation effects, and attention as well as to understand how different designs impact users with varying levels of insomnia.

Methods: The study was conducted in two phases. The first phase involved a questionnaire on the four guidance mechanisms. In the second phase, 33 participants classified by insomnia severity completed a sleep self-efficacy scale. They then engaged in five minutes of diaphragmatic breathing using each of the four interfaces. Relaxation effects were measured using heart rate variability via a smartwatch, attention and relaxation levels via an EEG device, and respiratory rate via a smartphone. Participants also completed the Game Experience Questionnaire and NASA-TLX, followed by user interviews.

Results: The results indicated that competence, immersion, tension, and challenge significantly influenced cognitive load. Specifically, competence and immersion reduced cognitive load, while tension and challenge increased cognitive load. Additionally, challenge and negative affect were shown to impact relaxation, with higher challenge levels correlating with increased respiratory rates and negative affect positively correlating with mean RMSSD. Cognitive load was found to affect both relaxation and attention, with a negative correlation between mental demand and attention and a positive correlation between temporal demand and respiratory rate. Sleep self-efficacy was negatively correlated with temporal demand and negative affect and positively correlated with competence and immersion.

Conclusions: Interfaces offering moderate variability and neither overly abstract nor too concrete guidance are preferable. The up/down interface was most effective, showing the best overall relaxation effect. Conversely, the number countdown interface was stress-inducing, while the zoom in/out interface had a significant impact on insomnia-related issues, making them less suitable for insomnia-related breathing exercises. Participants showed considerable variability in their response to the color gradient interface. These findings underscore the importance of carefully considering game design elements in relaxation training. It is essential that breathing guidance designs account for the impact of game experience to effectively promote relaxation in users.

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Diaphragmatic Breathing Interfaces to Promote Relaxation in Brief Behavioral Treatment for Insomnia: A Pilot Study

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Background: Brief behavioral treatment for insomnia is an effective short-term therapy focusing on stimulus control and sleep restriction to enhance sleep quality. As a crucial part of this therapy, diaphragmatic breathing is often recommended when patients fail to fall asleep within 30 minutes. With the rise of health applications and gamification, these tools are increasingly seen as effective ways to boost self-efficacy and user engagement; however, traditional games tend to increase attention, which can negatively impact sleep and contradicts the aim of sleep therapy. This study thus explored the potential for gamification techniques to promote relaxation without disrupting sleep processes.
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Conclusions: Interfaces offering moderate variability and neither overly abstract nor too concrete guidance are preferable. The up/down interface was most effective, showing the best overall relaxation effect. Conversely, the number countdown interface was stress-inducing, while the zoom in/out interface had a significant impact on insomnia-related issues, making them less suitable for insomnia-related breathing exercises. Participants showed considerable variability in their response to the color gradient interface. These findings underscore the importance of carefully considering game design elements in relaxation training. It is essential that breathing guidance designs account for the impact of game experience to effectively promote relaxation in users.

KEYWORDS

Brief Behavioral Treatment for Insomnia (BBTI); Sleep Self-Efficacy; Mobile Health; Breathing Training Cognitive Load; Attention; Gamification

Introduction

Insomnia is an increasingly severe issue, with approximately 30% of the population experiencing related symptoms [1]. It is characterized by difficulty in falling asleep, maintaining sleep, or waking up too early and being unable to return to sleep for at least three nights a week. This definition is based on the DSM-5 criteria. Acute insomnia lasts for one month, while chronic insomnia persists for over three months [2]. Cognitive behavioral therapy for insomnia (CBT-I) is the most common behavioral treatment [3]. CBT-I typically involves four to eight sessions focusing on changing thoughts, emotions, and behaviors related to sleep [4]. Derived from CBT-I, the brief behavioral treatment for insomnia (BBTI) condenses the process into four weeks, focusing on sleep restriction and stimulus control [5]. Compared to CBT-I, BBTI requires less time and resources, making it accessible to a wider range of patients.

Many people attempt to compensate for poor sleep patterns by spending excessive time in bed, which often increases anxiety about sleep. Sleep restriction reduces the time spent in bed to approximately match the actual sleep time, while stimulus control helps to reestablish the connection between the bed and sleep, reducing anxiety and frustration. If patients find themselves unable to sleep after 30 minutes in bed, they are advised to get up and engage in relaxing activities like deep breathing or stretching until they feel sleepy again [4]. Relaxation training is an important adjunct to insomnia treatment, particularly diaphragmatic breathing. Slow breathing can regulate the autonomic nervous system, increasing heart rate variability (HRV) and electroencephalogram (EEG) α power, leading to a state of calm and relaxation [6].

Many health applications focus on insomnia treatment, such as sleep diaries; however, there are few relaxation training apps specifically designed for insomniacs. The main challenge for health applications is ensuring long-term regular usage. In this endeavor, understanding user needs is crucial [7]. Users initially engage with health applications to meet health needs, but over time, enjoyment becomes increasingly important [8]. Gamification, which involves adding interactive elements to non-game contexts [9], is often used in health applications to attract patients through engaging interactions, promote adherence, and facilitate positive behavioral change [10].

Albert Bandura proposed the theory of self-efficacy, which refers to the ability to perceive oneself as being able to achieve a goal. This theory is used to measure the degree or strength of an individual's belief in their ability to accomplish a task [11]. Feedback from games can enhance self-efficacy, thereby affecting user participation and persistence in activities [12]. Virtual-reality biofeedback games can help to increase self-efficacy and reduce stress; there is evidence that higher self-efficacy is correlated with an increased ability to relax post-gaming [13]. Enhanced self-efficacy also supports adherence to BBTI, while low self-efficacy is associated with poorer compliance with stimulus control therapy and sleep hygiene [14].

Sleep self-efficacy, an extension of general self-efficacy, measures an individual's perceived ability to influence their own sleep behavior to achieve healthy sleep. The Sleep Self-Efficacy Scale, which comprises nine items, assesses this perception [15]. As insomnia severity, poor health, depression, and misconceptions about sleep increase, sleep self-efficacy decreases [16]. Both general self-efficacy and sleep self-efficacy are predictors of sleep health, with higher levels associated with better sleep quality, regularity, and scheduling [17].

The concept of cognitive load was proposed by Sweller [18]. It is based on the assumption that human cognitive resources are limited and that excessive cognitive load may affect the effectiveness of learning and task performance. Increased cognitive load before sleep can lead to arousal and longer sleep latency, affecting sleep quality [19]. Attention is also closely linked to sleep; the cognitive model of insomnia suggests that insomniacs often over-concern themselves with sleep, focusing attention on perceived sleep threats, such as bodily sensations or environmental factors, which can increase arousal and anxiety, leading to misconceptions that disrupt sleep [20]. Sleep should be an unconscious process [21]. Conscious attempts to fall asleep may disrupt sleep, and insomniacs are more likely than good sleepers to have difficulty falling asleep due to anxiety and environmental disruptions. Insomniacs are also more likely to think about not being able to fall asleep or things that have happened during the day before they go to bed. Using the NASA-TLX scale to assess the association between serious gaming and cognitive load [22], Sevcenko found that both task complexity and scene difficulty affected subjects' cognitive load and impacted gaming performance.

With the proliferation of health applications and medical gamification, gamifying relaxation training has become an effective way to enhance training outcomes. Many applications target breathing training; however, few focus on insomnia patients and pre-sleep use. Traditional games often increase attention or excitement, which can interfere with sleep. Therefore, this study explored guidance methods that do not affect sleep onset, increasing the interactivity of breathing guidance through engaging interface design to not only attract users and enhance participation and adherence but also identify designs that improve sleep self-efficacy. The selected variables were cognitive load, attention, gaming experience, and relaxation levels achieved through breathing guidance.

Methods

Four guidance mechanisms

In this study, various breathing-related games were categorized into four guidance mechanisms: countdown, zoom in/out, up/down movements, and color gradients. These methods range from concrete to abstract guidance and from small to large visual variations.

1. Countdown: Guidance is provided through a numerical countdown on the screen.
2. Zoom in/out: Guidance is provided through the enlargement and reduction of a graphic, with enlargement indicating inhalation and reduction indicating exhalation.
3. Up/down movements: Guidance is provided through the vertical movement of the screen, with upward movement indicating inhalation and downward movement indicating exhalation.
4. Color gradients: Guidance is provided through changes in the color gradient on the screen.

Interface design

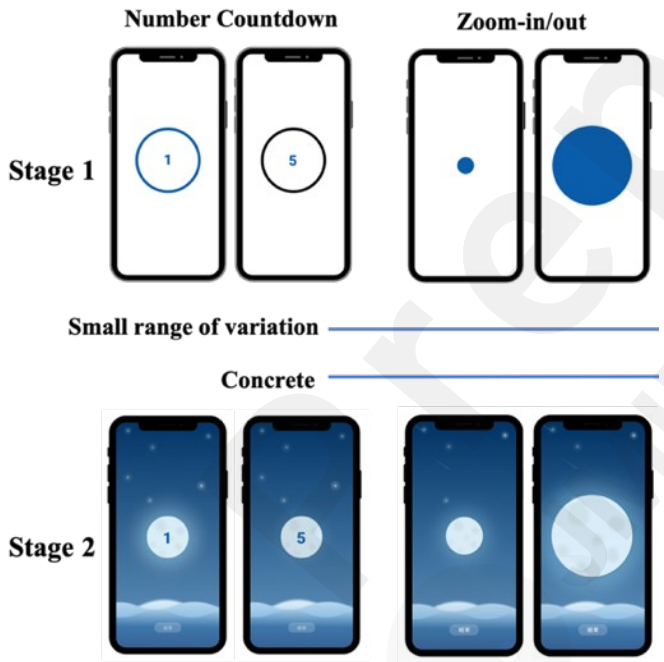
1. Main visuals: The game interface for relaxation training through diaphragmatic breathing features nighttime ocean waves as the main visual. The color blue is associated with many positive emotions, including relaxation, calmness, happiness, and comfort [23], because blue is often linked to natural elements such as the ocean, water, and sky, which evoke feelings of relaxation and tranquility. It has also been found that blue is the most favored color among Asian populations [24]. In addition, images of

natural landscapes produce higher levels of relaxation and are less stimulating than images of urban landscapes [25]. Among images of deserts, forests, snow, and water, researchers found images with water elements were the most relaxing [25].

2. Music: The game uses white noise from ocean waves combined with relaxing music as background audio. White noise has been proven to improve sleep quality by reducing environmental noise and inducing relaxation [26]. Compared to natural white noise, natural soundscapes, and ambient music, listening to instrumental music or instrumental music mixed with natural soundscapes has been found to be the most relaxing [27]. The combination of natural white noise and music enhances the sense of immersion and stimulates imagination. This allows subjects to visualize the natural environment in their mind, creating a sense of being in the natural environment, while the diversity of the music provides a better listening experience.

3. Guidance mechanism: Diaphragmatic breathing exercises are conducted in 5-minute sessions to ensure accurate HRV measurements [28]. The interface guides the user through six breaths per minute, as six breaths per minute achieves the highest HRV [29]. It also controls vagal activity, which helps insomniacs to maintain a stable sleep cycle and shorten the latency to sleep through regular breathing, improving the quality of sleep [30].

Figure 1. Prototypes of interface design for four guidance mechanisms



Measurement

In the experiment, we utilized a Garmin smartwatch to measure HRV and paired it with a BrainLink dynamic EEG headset (60 Hz) to assess relaxation and attention levels during gameplay. The Google Fit mobile application was used to measure breathing rates before and after the game sessions. All these devices were non-invasive and collected physiological signals from users during the relaxation game, which were then used for subsequent statistical analysis.

1. Breathing rate: The normal resting breathing rate for an adult is between 12-20 breaths per minute. However, breathing at a rate of six breaths per minute has been shown to achieve the highest HRV. Therefore, this study measured the changes in breathing rates before and after using the interface to determine which guiding method is most effective in reducing breathing rates.

2. Relaxation level: HRV is an indicator of relaxation. The standard deviation of NN intervals (SDNN) is used for assessing overall variability and heart health, whereas the root mean square of successive differences (RMSSD) is more influenced by the parasympathetic nervous system and is a suitable method for quantifying short-term HRV [31,32]. Alpha power are closely related to psychological relaxation states. Alpha power activity increases significantly when the individual is in a relaxed state. EEG data can also reflect specific psychological and emotional states [33,34,35,36]. Using a smartwatch to measure heart rate and HRV provides a direct reflection of physiological states, while EEG data reveal psychological relaxation activities and changes in attention during the relaxation process.

Questionnaire

1. Insomnia Severity Index (ISI) [37]: This scale assessed the severity of insomnia in participants. Scores ranging from 0-7 indicate "no insomnia"; scores ranging from 8-14 indicate "mild insomnia"; and scores of 15 and above indicate

"moderate to severe insomnia".

2. NASA Task Load Index [38]: This scale evaluated the cognitive load experienced by users under different breathing guidance methods during the diaphragmatic breathing game. It consists of six items measuring mental, physical, and temporal demands as well as performance, effort, and frustration. Scores range from 0 to 100, with lower scores indicating better performance or lower subjective load in each dimension.
3. AttrakDiff Mini: AttrakDiff [39] is a tool used to assess user experience, analyzing the pragmatic quality (PQ), hedonic quality-stimulation (HQ-S), hedonic quality-identity (HQ-I), and attractiveness (ATT) of interactive products. The full scale contains 28 items, while the AttrakDiff Mini reduces this to 10 items. This study used a seven-point scale (-3: negative, 3: positive) to measure the PQ, HQ-S, HQ-I, and ATT of the interfaces.
4. Sleep Self-Efficacy Scale [15]: This scale consisted of nine items assessing participants' confidence in their ability to sleep.
5. Game Experience Questionnaire (GEQ) [40]: The GEQ assessed players' game experiences, containing 33 items covering seven dimensions: competence, sensory and imaginative immersion, flow, tension, challenge, negative affect, and positive affect. This study used the GEQ to evaluate subjective game experiences across different game guidance methods and to analyze which aspects of the game influence relaxation.

Experimental procedure

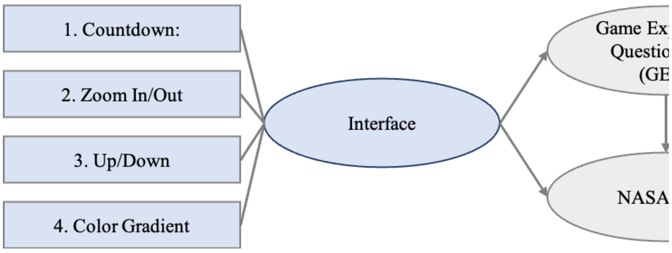
The questionnaire items covered age, gender, work status, and past experience with relaxation applications. Afterwards, the participants watched videos of the four different breathing modalities, each of which was a 30-second video of each of the four interfaces, and then filled out the NASA-TLX Workload Scale and the AttrakDiff Mini scale to assess the cognitive load and experience of each modality. This process was repeated four times, once for each breathing guidance method. Based on the results and feedback from the first phase, the diaphragmatic breathing interfaces were refined and improved.

In the second phase, participants were recruited to perform 5-minute diaphragmatic breathing sessions. Participants included individuals with no insomnia, mild insomnia, and severe insomnia. They first completed a basic information form, which included demographic data, the ISI, and the Sleep Self-Efficacy Scale. Participants wore a Garmin smartwatch to collect HRV and a BrainLink Dynamic Brainwave Instrument to measure mental relaxation and attention as well as used a cell phone app, Google Fit, to measure respiratory rate before and after the experiment. Using a Latin square design to randomize the order, participants performed diaphragmatic breathing exercises with four different interfaces, each for 5 minutes. After each session, participants completed the NASA-TLX scale and the GEQ to evaluate the cognitive load and user experience of each interface. Upon completing all sessions, semi-structured interviews were conducted to gather feedback on the design of the game mechanisms and preferences as well as explore possible reasons for relaxation during the game. This experimental design allowed for a comprehensive evaluation of how participants with varying insomnia severity responded to the four breathing guidance methods, using both physiological signals and subjective assessments to identify the most effective relaxation training methods. Figure 2 shows the correlogram of the second stage of the experiment, which assessed the response of subjects with different severities of insomnia to the four types of breathing guidance, and identified the most effective relaxation training method through physiological signals and subjective ratings.

Participants

The study was approved by the TMU-Joint Institutional Review Board of Taipei Medical University and its affiliated hospital under the general review case number N20243070. Before participating in the second phase of the experiment, all subjects signed consent forms, indicating their full understanding of the contents of the experiment and their agreement to participate. Participants with varying degrees of insomnia, including none, mild, and severe insomnia, were recruited through social media at Taipei University of Technology and the Taipei Tech Student Counseling Center. Exclusion criteria included the following: individuals diagnosed with epilepsy, arrhythmia or other heart diseases, current respiratory system diseases, or other untreated sleep-related issues; individuals diagnosed with psychiatric disorders requiring treatment; individuals with substance abuse or alcohol addiction; night shift workers; pregnant or breastfeeding women, women with severe menopause symptoms; and individuals under guardianship or assistance declarations.

Figure 2. Second phase: correlation between questionnaires and physiological signals

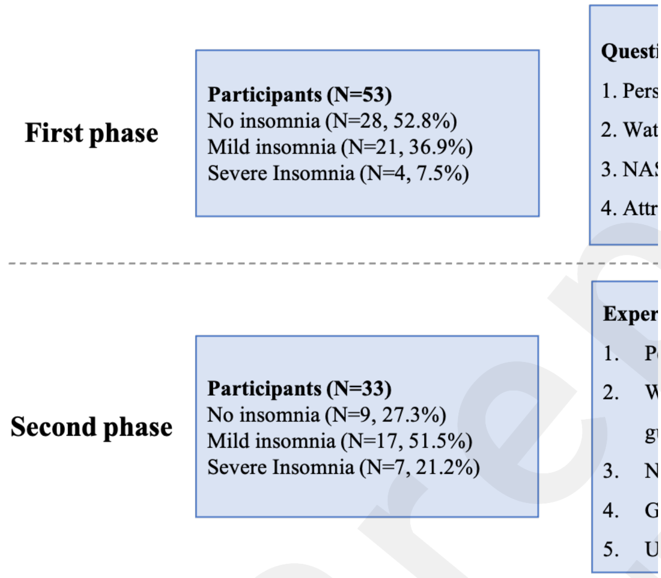

1. Countdown:
2. Zoom In/Out
3. Up/Down
4. Color Gradient
Interface
NASA

Results

Overview

In the first phase of the breathing guidance prototype survey, conducted between January and February 2024, a total of 53 valid questionnaires were collected. The participants ranged in age from 18 to 65 years and included both genders. Among them, 28 participants had no insomnia (52.8%), 21 had mild insomnia (36.9%), and 4 had severe insomnia (7.5%). In the second phase of the interface design experiment, conducted from May to July 2024, 33 participants were recruited, ranging in age from 20 to 65 years, including both genders, without excluding any participants. Among these participants, 9 had no insomnia (27.3%), 17 had mild insomnia (51.5%), and 7 had severe insomnia (21.2%). The experimental steps and the number of subjects are shown in Figure 3. Among these participants, 9 had no insomnia (27.3%), 17 had mild insomnia (51.5%), and 7 had severe insomnia (21.2%). The experimental steps and the number of subjects are shown in Figure 3.

Figure 3. Number of participants and experimental procedure for two-phase study



Changes in breathing rate

As shown in Table 1, breathing rates decreased the least (1.13) after participants used the zoom in/out interface. Breathing rates decreased respectively by 1.41 and 1.53 after participants used the countdown interface and the up/down interface. Breathing rates decreased the most (1.75) after participants used the color gradient interface. Paired sample T-tests were used to analyze breathing rates before and after the intervention. There was a significant difference in breathing rates before and after participants used the up/down interface ($p = .038$) and the color gradient interface ($p = .018$). This indicates that these two guidance methods can effectively regulate breathing frequency through relaxation training.

Table 1. Comparison of breathing rates before and after diaphragmatic breathing training

Interface style	Mean (pre-training)	Mean (post-training)	Mean (difference)	Standard deviation	95% Confidence interval		t-value	Significance (two-tailed)
					Lower bound	Upper bound		
Countdown	13.47	12.06	1.41	4.063	-.059	2.871	1.958	.059
Zoom in/out	12.91	11.78	1.13	4.549	-.515	2.765	1.399	.172
Up/down	13.00	11.47	1.53	3.992	.092	2.970	2.170	.038*
Color gradients	13.34	11.59	1.75	3.976	.317	3.183	2.490	.018*

Interface measurement

Figure 4 describes the average cognitive load, usage experience, and gaming experience of the four pre-test interventions. According to the NASA-TLX(1) results from the first phase of the experiment, the cognitive load induced by the countdown interface and the up/down interface was 39.86 and 35.14, respectively. The zoom in/out interface induced the lowest cognitive load at an average of 29.72, while the color gradient interface induced the highest cognitive load at an average of 43.35. The AttrakDiff Mini results showed that overall satisfaction was the lowest for the countdown interface, particularly in HQ-I and HQ-S scores, which were negative. The zoom in/out interface had the highest overall satisfaction, while the color gradient interface had the lowest PQ among the four interfaces.

In the second phase of the experiment, the NASA-TLX(2) results showed that the countdown interface induced the highest overall cognitive load, with high scores in psychological, physical, time, and frustration loads. The zoom in/out interface induced the second-highest cognitive load, with the highest scores in performance and effort, indicating that this interface led to poorer performance and required more effort. The up/down interface induced the second lowest overall cognitive load, with the lowest scores in time pressure, effort, and frustration. The color gradient interface induced the lowest cognitive load, with the lowest scores in psychological, physical, and performance loads, indicating that it was less likely to cause psychological and physical strain.

Figure 4. Mean values of NASA-TLX, Attrakdiff Mini, and Game Experience Questionnaire across four interfaces

Physiological measurements

Table 2 illustrates the results of relaxation measurements from the second phase. The data included the average respiratory rate per minute after 5 minutes of diaphragmatic breathing, average heart rate, average SDNN, and average RMSSD measured during diaphragmatic breathing using a smartwatch as well as relaxation level, relaxation stability, attention, and attention stability measured using an EEG device. For the up-down interface, the respiratory rate and average heart rate were the lowest while the average RMSSD was the highest, indicating that the up-down interface provides better breathing guidance and relaxation effects. Additionally, the zoom in/out interface showed the highest psychological relaxation, the up-down interface had the highest relaxation stability and attention stability, and the color gradient interface had the highest attention.

Table 2. Physiological and psychological measurements of four interfaces

Interface style	Physiological signal	Minimum	Maximum	Mean (SD)

Countdown	Breathing rate	6	22	12.06 (3.98)
	Mean heart rate	62	107	81.58 (10.12)
	Mean SDNN	9.89	90.41	45.74 (16.09)
	Mean RMSSD	15.75	74.84	29.37 (12.08)
	Relaxation	28	66	52.85 (7.95)
	Relaxation stability	42	77	52.15 (6.15)
	Attention	33	72	51.94 (9.09)
	Attention stability	20	77	55.79 (12.46)
Zoom in/out	Breathing rate	6	24	11.78 (4.76)
	Mean heart rate	66	110	81.03 (10.25)
	Mean SDNN	29.77	102.18	50.43 (16.88)
	Mean RMSSD	15.79	63.29	31.55 (11.28)
	Relaxation	42	71	56.30 (8.60)
	Relaxation stability	43	60	51.42 (4.02)
	Attention	34	68	52.12 (7.47)
	Attention stability	31	79	57.00 (10.70)
Up/down	Breathing rate	6	20	11.47 (4.12)
	Mean heart rate	64	108	80.36 (10.57)
	Mean SDNN	29.70	86.17	50.22 (16.24)
	Mean RMSSD	11.85	60.28	33.06 (12.21)
	Relaxation	34	68	55.48 (7.76)
	Relaxation stability	45	62	52.82 (4.33)
	Attention	34	73	52.24 (9.57)
	Attention stability	44	73	59.24 (8.39)
Color gradients	Breathing rate	6	24	11.59 (4.85)
	Mean heart rate	58	113	80.94 (11.13)
	Mean SDNN	26.17	107.45	50.56 (16.67)
	Mean RMSSD	12.29	77.00	32.47 (14.08)
	Relaxation	43	69	55.70 (6.79)
	Relaxation stability	41	67	50.88 (5.41)
	Attention	37	73	52.33 (9.95)
	Attention stability	26	77	57.85 (10.03)

Impact of gaming experience on cognitive load

Table 3 presents the results of MANOVA analysis. We compared the seven dimensions of game experience to assess their impact on cognitive load, followed by partial correlation analysis. The results indicate that competence, immersion, flow, tension, challenge, and positive affect significantly influenced overall cognitive load. The specific effects of each dimension are detailed below.

Competence significantly impacted mental load ($F(1, 131) = 12.639$, $p = .001$) with a notable negative correlation ($r = -.301$, $p < .001$) and temporal load ($F(1, 131) = 4.660$, $p = .033$) with a significant negative correlation ($r = -.384$, $p < .001$). In addition, competence significantly influenced performance ($F(1, 131) = 9.902$, $p = .002$) and frustration ($F(1, 131) = 10.168$, $p = .002$), both with negative correlations ($r = -.542$, $p < .001$) and ($r = -.554$, $p < .001$), respectively.

Immersion affected mental load ($F(1, 131) = 9.523$, $p = .003$) with a significant negative correlation ($r = -.240$, $p = .006$); though there was an impact on physical load ($F(1, 131) = 5.523$, $p = .019$), this did not show a significant partial correlation. Immersion also influenced effort ($F(1, 131) = 6.385$, $p = .013$) with a negative correlation ($r = -.272$, $p = .002$), indicating that a stronger degree of immersion reduces cognitive load.

Flow impacted mental load ($F(1, 131) = 5.296$, $p = .023$) but had no significant partial correlation, suggesting a weaker influence when controlling for interface variables.

Tension significantly affected frustration ($F(1, 131) = 4.459$, $p = .037$) with a positive correlation ($r = .573$, $p < .001$).

Challenge significantly influenced performance ($F(1, 131) = 5.649$, $p = .019$), effort ($F(1, 131) = 17.471$, $p < .001$), and frustration (F(1, 131) = 8.012, p = .005), all exhibiting significant positive correlations (r = .422, p < .001), (r = .441, p < .001), and (r = .586, p < .001), respectively. Positive affect influenced mental load (F(1, 131) = 7.264, p = .008) and physical load (F(1, 131) = 4.187, p = .043); however, the partial correlations were not significant, indicating a weaker direct impact under different interface conditions. Overall, higher levels of competence and immersion reduced cognitive load, while higher levels of tension and challenge increased cognitive load.

Table 3. Influence and correlations among gaming experience and cognitive load

Source	Dependent variable	Type-III sum of squares	df	F	P value	Correlation	Significance (two-tailed test)
Competence	Mental demand	5351.446	1	12.639	.001**	-.301	.000***
	Physical demand	1569.405	1	2.836	.095	-.190	.029*
	Temporal demand	2950.515	1	4.660	.033*	-.395	.000***
	Performance	2779.322	1	9.902	.002**	-.547	.000***
	Effort	1247.794	1	3.050	.083	-.367	.000***
	Frustration	3089.548	1	10.168	.002**	-.561	.000***
Immersion	Mental demand	4031.913	1	9.523	.003**	-.240	.006**
	Physical demand	3102.594	1	5.606	.019*	-.116	.186
	Temporal demand	271.346	1	.429	.514	-.203	.019*
	Performance	365.255	1	1.301	.256	-.259	.003**
	Effort	2611.819	1	6.385	.013*	-.278	.001**
	Frustration	483.841	1	1.592	.209	-.216	.013**
Flow	Mental demand	2242.221	1	5.296	.023*	.014	.873
	Physical demand	1972.251	1	3.563	.061	.179	.040*
	Temporal demand	248.462	1	.392	.532	.355	.000***
	Performance	226.003	1	.805	.371	.342	.000***
	Effort	411.573	1	1.006	.318	.213	.014*
	Frustration	49.097	1	.162	.688	.541	.000***
Tension	Mental demand	9.014	1	.021	.884	.146	.095
	Physical demand	440.299	1	.796	.374	.170	.052
	Temporal demand	188.720	1	.298	.586	.348	.000***
	Performance	19.737	1	.070	.791	.337	.000***
	Effort	765.887	1	1.872	.174	.209	.016*
	Frustration	1354.865	1	4.459	.037*	.537	.000***
Challenge	Mental demand	95.559	1	.226	.636	.303	.000***
	Physical demand	1987.804	1	3.592	.060	.410	.000***
	Temporal demand	2051.889	1	3.241	.074	.422	.000***
	Performance	1585.515	1	5.649	.019*	.441	.000***
	Effort	7146.780	1	17.471	.000***	.586	.000***
	Frustration	2434.481	1	8.012	.005**	.303	.000***
Positive affect	Mental demand	3075.426	1	7.264	.008**	-.130	.138
	Physical demand	2317.192	1	4.187	.043*	.017	.847
	Temporal demand	999.289	1	1.578	.211	-.224	.010*
	Performance	531.233	1	1.893	.171	-.390	.000***
	Effort	277.035	1	.677	.412	-.198	.023*
	Frustration	39.823	1	.131	.718	-.357	.000***

Impact of cognitive load on relaxation

We compared the six dimensions of cognitive load on relaxation, with MANOVA and partial correlation analysis results presented in Table 4.

MANOVA results indicate that mental demand and temporal demand were the primary factors influencing relaxation. Mental demand significantly affected attention (F(1, 126) = 13.395, p < .001), with a strong negative correlation (r = -.308, p < .001); in other words, higher mental demand corresponds to lower attention. Temporal demand significantly impacted breathing rate (F(1, 126) = 7.900, p = .006), with a significant positive correlation (r = .245, p = .005); thus, higher temporal demand increases breathing rate.

Table 4. Impact of cognitive load on relaxation

Source	Dependent variable	Type-III sum of squares	df	F	P value	Correlation	Significance (two-tailed test)
Mental demand	Breathing rate	1.907	1	.100	.752	.077	.393
	Mean heart rate	35.837	1	.315	.576	-.094	.294
	Mean SDNN	102.886	1	.384	.537	.185	$.038^{*}$
	Mean RMSSD	5.282	1	.034	.853	.101	.260
	Relaxation	153.954	1	2.599	.110	.000	.996
	Relaxation stability	1.254	1	.050	.824	.027	.763
	Attention	1023.084	1	13.395	$.000^{***}$	-.308	$.000^{***}$
	Attention stability	37.647	1	.343	.559	.146	.101
Temporal demand	Breathing rate	150.469	1	7.900	$.006^{**}$	.245	$.005^{**}$
	Mean heart rate	31.999	1	.281	.597	.004	.968
	Mean SDNN	4.437	1	.017	.898	.073	.417
	Mean RMSSD	12.672	1	.082	.775	.017	.850
	Relaxation	206.818	1	3.491	.064	.159	.074
	Relaxation stability	10.821	1	.429	.514	-.017	.853
	Attention	89.323	1	1.169	.282	-.072	.423
	Attention stability	65.535	1	.598	.441	.116	.194

Impact of gaming experience on relaxation

Results from MANOVA and partial correlation analyses are shown in Table 5. The study compared whether game experience influences relaxation. The statistical results indicate that flow, tension, challenge, and negative affect were the main gaming elements affecting overall relaxation. Flow significantly affected mean heart rate (F(1, 126) = 7.926, p = .006), mean SDNN (F(1, 126) = 8.132, p = .005), mean RMSSD (F(1, 126) = 11.171, p = .001), and attention (F(1, 126) = 7.420, p = .007). However, partial correlation analysis revealed no significant correlations between flow and these four variables, indicating a weak direct impact after controlling for different interface variables.

Tension significantly affected mean heart rate (F(1, 126) = 6.938, p = .010); however, there was no significant correlation. Challenge also significantly affected attention (F(1, 126) = 5.698, p = .019) and attention stability (F(1, 126) = 4.666, p = .033); partial correlation analysis revealed no significant correlations between challenge and these variables, indicating a weak direct impact after controlling for different interface variables.

Negative affect significantly affected mean RMSSD (F(1, 126) = 4.809, p = .010). Partial correlation analysis showed a significant positive correlation between negative affect and mean RMSSD (r = .225, p = .010), indicating that a higher level of negative affect correlates with a higher mean RMSSD.

Table 5. Impact of gaming experience on relaxation

Source	Dependent variable	Type-III sum of squares	df	F	P value	Correlation	Significance (two-tailed test)
Flow	Breathing rate	.291	1	.015	.902	-.083	.355
	Mean heart rate	796.154	1	7.926	.006**	-.081	.367
	Mean SDNN	2082.370	1	8.132	.005**	.063	.481
	Mean RMSSD	1516.428	1	11.171	.001**	.006	.946
	Relaxation	3.515	1	.058	.811	-.021	.814
	Relaxation stability	.007	1	.000	.986	.096	.280
	Attention	586.024	1	7.420	.007**	-.076	.393
	Attention stability	.156	1	.001	.970	.026	.769
Tension	Breathing rate	.935	1	.049	.825	.227*	.010**
	Mean heart rate	696.960	1	6.938	.010*	.047	.599
	Mean SDNN	447.021	1	1.746	.189	.025	.778
	Mean RMSSD	328.948	1	2.423	.122	.087	.332
	Relaxation	36.136	1	.591	.443	.150	.093
	Relaxation stability	47.271	1	1.936	.167	-.251**	.004**
	Attention	67.353	1	.853	.358	-.022	.809
	Attention stability	37.167	1	.347	.557	.010	.914
Challenge	Breathing rate	81.613	1	4.301	.040*	.296**	.001**
	Mean heart rate	60.141	1	.599	.441	-.046	.604
	Mean SDNN	34.059	1	.133	.716	.098	.274
	Mean RMSSD	1.370	1	.010	.920	.106	.237
	Relaxation	51.521	1	.843	.360	.154	.083
	Relaxation stability	.377	1	.015	.901	-.182*	.041*
	Attention	450.051	1	5.698	.019*	.126	.160
	Attention stability	499.993	1	4.666	.033*	.167	.060
Positive affect	Breathing rate	1.157	1	.061	.805	.177*	.046*
	Mean heart rate	691.080	1	6.880	.010*	-.133	.137
	Mean SDNN	436.333	1	1.704	.194	.106	.237
	Mean RMSSD	652.855	1	4.809	.030*	.225*	.011
	Relaxation	3.695	1	.060	.806	.103	.247
	Relaxation stability	36.853	1	1.510	.222	-.229*	.010**
	Attention	44.949	1	.569	.452	-.062	.489
	Attention stability	420.980	1	3.928	.050	-.087	.333

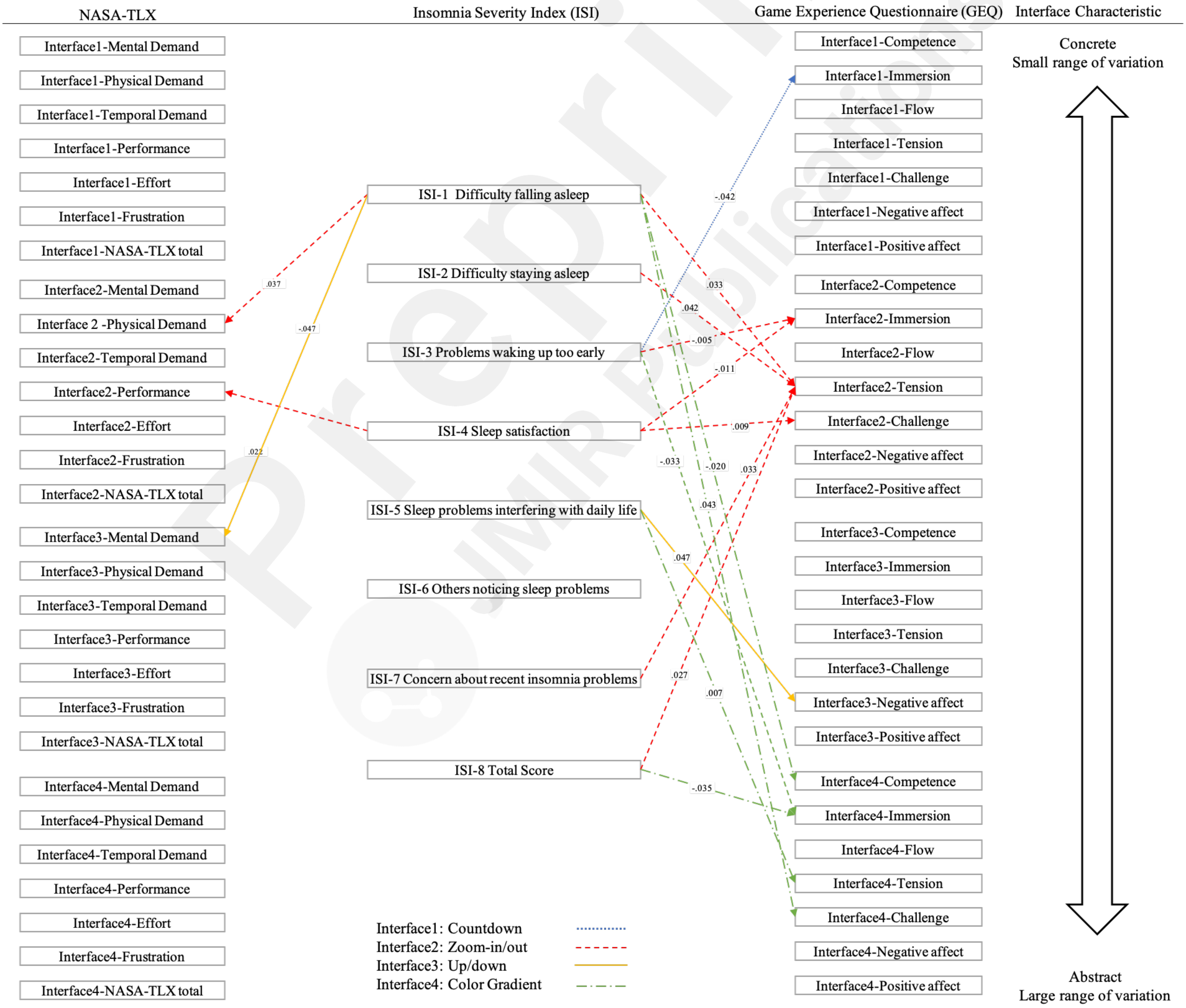
Correlation between cognitive load and insomnia severity

As shown in Figure 5, the correlation between cognitive load and insomnia severity was low. Difficulty falling asleep was positively correlated with the physical demand of the zoom in/out interface (r = .364, p = .037) and negatively correlated with the mental demand of the up/down interface (r = -.348, p = .047). Thus, it seems that the up/down interface exerts a lower mental demand on individuals who experience difficulty falling asleep.

There was a negative correlation between participants who had problems waking up too early and immersion when using the countdown (r = -.356, p = .042), zoom in/out (r = -.481, p = .005), and color gradient (r = -.373, p = .033) interfaces, suggesting that immersion is a design element that can significantly impact insomnia severity. The zoom in/out interface showed a moderate positive correlation between tension and (ISI-1) difficulty falling asleep (r = .372, p = .033), (ISI-2) difficulty maintaining sleep (r = .357, p = .042), (ISI-7) concerns about recent insomnia (r = .372, p = .033), and the total ISI score (r = .385, p = .027). This indicates that participants with these sleep issues or higher overall insomnia severity scores experience higher levels of tension with the zoom in/out interface.

The negative affect triggered by the up/down interface was positively correlated with (ISI-5) sleep problems interfering with daily life (r = .348, p = .047), meaning that participants whose daily lives are more affected by sleep problems experienced higher negative affect with this interface. For the color gradient interface, there was a positive correlation between tension and (ISI-5) sleep problems interfering with daily life (r = .464, p = .007). The correlations between the zoom in/out and insomnia severity and between color gradient interfaces and insomnia severity indicate that these two guidance designs are more susceptible to variations based on insomnia severity and are therefore less suitable for insomnia-related game design.

Figure 5. Correlations among insomnia severity, cognitive load, and gaming experience for four interfaces (countdown, zoom in/out, up/down, and color gradients)



Sleep self-efficacy correlation analysis

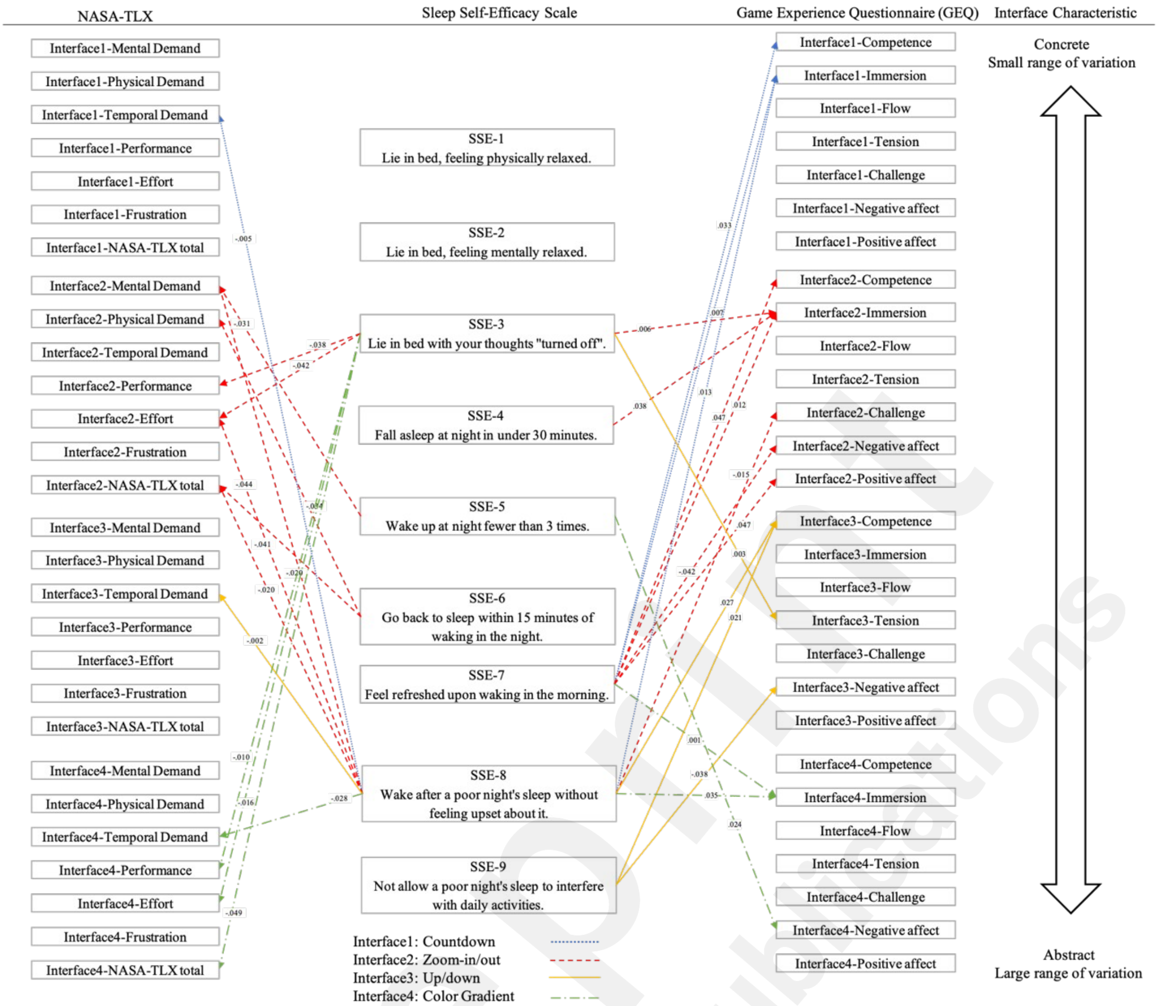
As shown in Figure 6, the temporal demand of the countdown (r = -.474, p = .005), up/down (r = -.512, p = .002), and color gradient (r = -.381, p = .028) interfaces were significantly negatively correlated with 'wake after a poor night's sleep without feeling upset about it' (SSE-8). This indicates that participants with lower sleep self-efficacy experienced higher temporal demand in these interfaces. Therefore, temporal demand is a factor that easily affects sleep self-efficacy, and special attention should be paid to the stress caused by time factors in the design of diaphragmatic breathing guides.

The cognitive load of the color gradient interface was significantly negatively correlated with 'lie in bed with thoughts turned off' (SSE-3). This suggests that this guidance mechanism significantly affects pre-sleep self-efficacy, as the abstract and wide-ranging visual changes of the color gradient interface require more effort to understand and adapt to, resulting in higher cognitive load for those who cannot calm their minds before sleep. Overall, the cognitive load of the zoom in/out interface was negatively correlated with many aspects of sleep self-efficacy; the lower the sleep self-efficacy, the higher the cognitive load when using the zoom in/out interface.

There were many correlations between the seven dimensions of the GEQ and sleep self-efficacy, especially with the items 'feel refreshed upon waking in the morning' (SSE-7) and 'wake after a poor night's sleep without feeling upset about it' (SSE-8), indicating that there is a relationship between game design elements and mental states upon waking. Competence and immersion were the two game dimensions most related to sleep self-efficacy. 'Feel refreshed upon waking in the morning' (SSE-7) was positively correlated with competence ($r = .372$, $p = .033$) and immersion ($r = .458$, $p = .007$) for the countdown interface, competence ($r = .348$, $p = .047$) and immersion ($r = .434$, $p = .012$) for the zoom in/out interfaces, and immersion ($r = .567$, $p = .001$) for the color gradient interface. 'Waking after a poor night's sleep without feeling upset about it' (SSE-8) was positively correlated with immersion for the countdown interface ($r = .427$, $p = .013$), competence ($r = .384$, $p = .027$) for the up/down interface, and immersion ($r = .368$, $p = .035$) for the color gradient interface. This indicates that higher competence or immersion in these interfaces correlated with higher self-efficacy upon waking up. Therefore, to improve sleep self-efficacy, game design should focus on enhancing players' sense of competence and immersion to provide a good relaxation training experience.

Negative affect also has an important impact on sleep self-efficacy. There was a significant positive correlation between negative affect triggered by the color gradient interface and 'wake up at night fewer than 3 times' (SSE-5) ($r = .393$, $p = .024$), a negative correlation between negative affect triggered by the zoom in/out interface and 'feel refreshed upon waking in the morning' (SSE-7) ($r = -.356$, $p = .042$), and a negative correlation between negative affect triggered by the up/down interface and 'wake after a poor night's sleep without feeling upset about it' (SSE-8) ($r = -.363$, $p = .038$). This indicates that negative affect can have both positive and negative impacts on sleep self-efficacy.

Figure 6. Correlations among sleep self-efficacy, cognitive load, and gaming experience for four interfaces (countdown, zoom in/out, up/down, and color gradients)



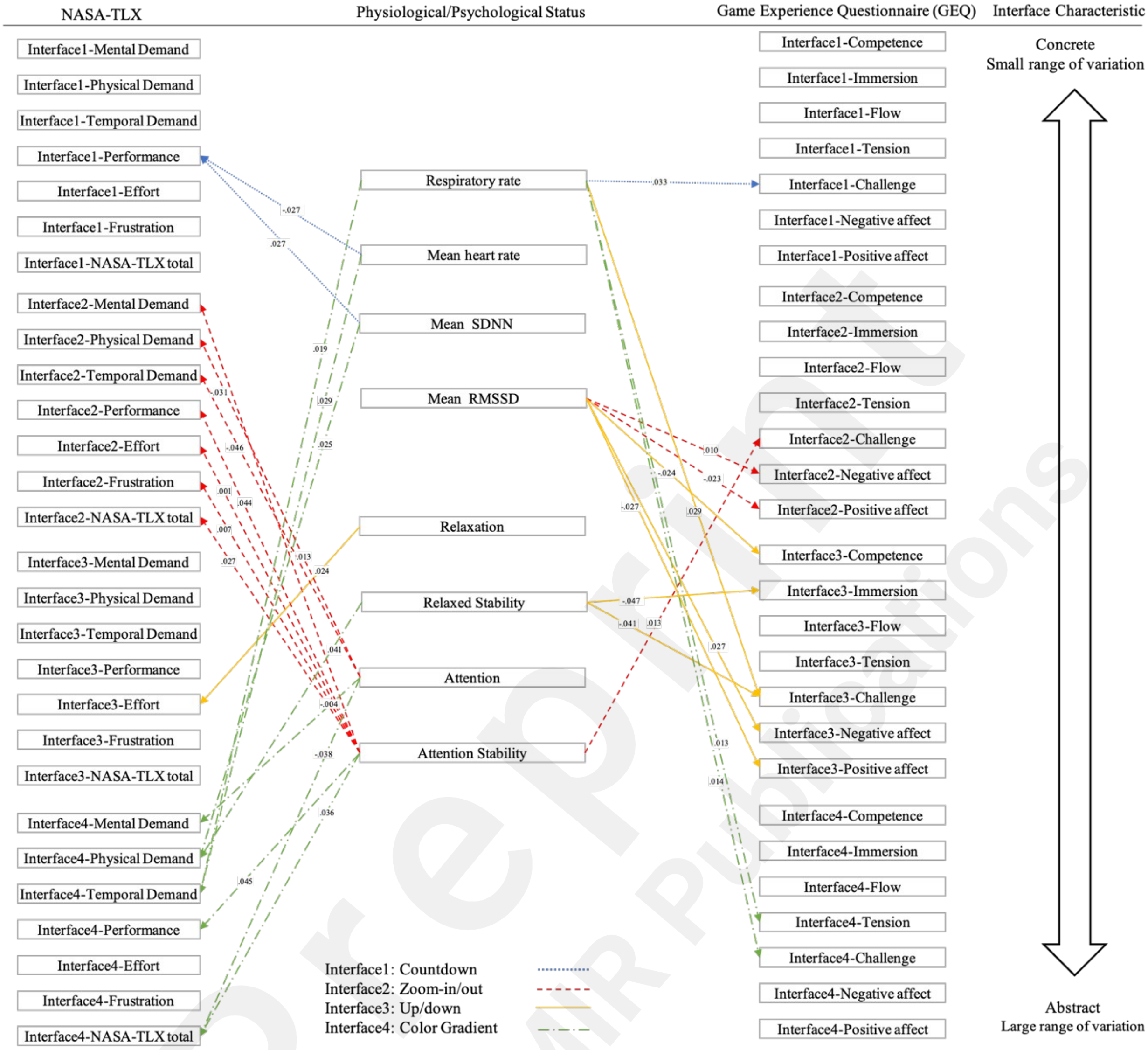
Physiological and psychological values

As shown in Figure 7, the countdown guidance mechanism had the most obvious effect on physiological states, particularly subjective performance as well as mean heart rate (r = -.385, p = .027) and mean SDNN (r = .385, p = .027). For the zoom in/out interface, attention was negatively correlated with mental demand (r = -.377, p = .031) and temporal demand (r = .350, p = .046). Additionally, attention stability exhibited positive correlations with mental load (r = .427, p = .013), effort (r = .539, p = .001), frustration (r = .458, p = .007), and overall score (r = .385, p = .027). The limited range and specific guidance of this interface likely influenced attention. The effort and relaxation associated with the up/down interface were positively correlated (r = .392, p = .024), indicating that the more effort participants put into training with this method, the higher their overall relaxation level. Therefore, the up/down interface is suitable for users training in diaphragmatic breathing for the first time.

The color gradient interface was correlated with both physiological and psychological states. Its abstract nature and broad variability may influence relaxation and attention, as the cognitive load required varies for each individual. Only the temporal demand of the color gradient was positively correlated with the breathing rate (r = .413, p = .019). Note that this guidance mechanism is the most abstract. If users feel time pressure during execution, their breathing rate will increase.

The challenge aspect of the game experience was highly correlated with the breathing rate. The challenge aspects of the countdown (r = .378, p = .033), up/down (r = .387, p = .029), and color gradient (r = .440, p = .014) interfaces were all positively correlated with the breathing rate, indicating that the level of challenge affected the users' breathing rate, with higher challenge levels leading to increased breathing rates. The most significant game experiences affecting average RMSSD were positive and negative affect. The average RMSSD of the zoom in/out interface was negatively correlated with positive affect (r = -.395, p = .023) and positively correlated with negative affect (r = .442, p = .010). The average RMSSD during the up/down interface was also negatively correlated with positive affect (r = -.385, p = .027) and positively correlated with negative affect (r = .384, p = .027). This suggests that higher negative affect can lead to higher relaxation levels because negative affect such as boredom or weariness also indicates lower stimulation. Thus, in a low-stimulation environment, people tend to feel more relaxed. Conversely, positive affect includes fun, enjoyment, or pleasure, which may shift attention to the game interface rather than the act of diaphragmatic breathing itself, leading to reduced physiological relaxation. Additionally, exciting and happy emotions might stimulate the sympathetic nervous system, reducing RMSSD.

Figure 7. Correlations among physiological/psychological signals, cognitive load, and gaming experience for four interfaces (countdown, zoom in/out, up/down, and color gradients)



Qualitative findings and implications

The study compiled interview results from 33 participants. Users felt that the countdown interface provided clear guidance. However, the rapid change of numbers disrupted their breathing rhythm, and the prolonged inhalation and exhalation periods made it difficult to follow the guide. The zoom in/out guidance mechanism is common in many apps, making it familiar and easy for users to understand and accept. However, care must be taken with the scale of the visual changes and the brightness of the colors, as excessive magnification or overly bright colors can cause visual strain. The up/down guidance, which mimics the natural rhythm of ocean waves, is visually soothing and facilitates relaxation, making it the preferred choice for most participants. When paired with music, it creates a sense of immersion, though the sensation of rising might cause some users to feel overwhelmed; therefore, it is crucial to consider the range of visual changes in the design. Users noted that the zoom in/out and up/down guidance mechanisms align well with the body's natural breathing patterns, enhancing comprehension and effectiveness. This finding supports that of Chuanromanee and Metoyer [41]. The color gradients, which are a more abstract guidance method, offered a high tolerance for error, which some users liked as it allowed them to match their own breathing rate, resulting in less pressure. However, the lack of clarity in the variations when first using this interface might disrupt the breathing rhythm, and the brightening colors could cause visual stimulation.

The effectiveness of different interfaces varies with individual differences. The interviews revealed that even with the same breathing rate, different guidance mechanisms gave users different perceptions of the rate, as visual animations, colors, and changes in size also affected subjective pressure and relaxation effects. Most participants felt that the initial stages were visually guided; however, after prolonged use, they shifted to auditory guidance. Therefore, visual and auditory guidance should complement each other, allowing users to become familiar with the breathing rate and subsequently continue with auditory guidance. Future app designs should incorporate more personalized options, such as selecting the breathing guidance rate, as many participants reported difficulty keeping up with the six breaths per minute initially. Enhancing auditory and visual changes, like voice and other animation guidance, should also be considered. Additionally, introducing stories or reward mechanisms could enrich the overall app experience and enhance user compliance with relaxation training.

Discussion

Principal findings

In our two-stage experiment, the first stage revealed that the zoom in/out interface demanded the lowest cognitive load and achieved the highest user experience score, while the color gradient interface demanded the highest cognitive load. However, in the second stage, the color gradient interface was reported to demand the lowest overall cognitive load, followed by the up/down interface, which was also associated with the lowest breathing rate and mean heart rate as well as the highest mean RMSSD. This indicates that the duration of the diaphragmatic breathing game affects cognitive load and relaxation. For short-term use, the zoom in/out interface incurs a lower cognitive load due to its moderate variation range and specific guidance, making it more effective initially. However, for longer durations, the more abstract up/down and color gradient interfaces are more effective, as they allow users to breathe at their own pace, reducing cognitive load and enhancing relaxation. The countdown had high cognitive load in both stages and low relaxation in the second stage, indicating that specific numerical guidance causes higher stress regardless of duration, leading to poor relaxation outcomes.

Countdown: This is the most specific guidance with the smallest range of variation, primarily related to physiological relaxation. Subjective performance with this interface is significantly correlated with mean heart rate and SDNN, especially when user performance is poor. Users with lower sleep self-efficacy experienced higher temporal demand, impacting relaxation. The immersion experience with this interface is negatively correlated with users troubled by waking too early, indicating that those with insomnia find it less immersive. Therefore, the applicability of numerical guidance in relaxation training games should be carefully considered.

Zoom in/out: This interface strikes a balance between abstract and specific guidance with a smaller range of variation. It shows more correlations between cognitive load and insomnia severity, indicating higher cognitive load for users with difficulty falling asleep and dissatisfaction with sleep. There is also a significant negative correlation between cognitive load and sleep self-efficacy, making it unsuitable for users with sleep onset difficulties. Cognitive load with this interface is significantly correlated with attention and attention stability, requiring higher attention stability to complete tasks, thus increasing overall cognitive load.

Up/down: This abstract interface with a larger range of variation shows no significant correlation between cognitive load and insomnia severity, sleep self-efficacy, or physiological and psychological relaxation, indicating that it is less influenced by differences in user groups and is thus suitable for most users. There is a negative correlation between difficulty falling asleep and mental demand for this interface, which indicates that it is more effective for those with sleep onset difficulties. Negative affect triggered by this interface is positively correlated with mean RMSSD, indicating that greater negative affect leads to higher levels of relaxation.

Color gradients: This interface is the most abstract with the largest range of variation. There is a significant negative correlation between cognitive load and the sleep self-efficacy item 'lie in bed with your thoughts turned off' (SSE-3), indicating that abstract and highly variable visual guidance requires more effort to understand and adapt to, leading to higher cognitive load. This interface is correlated with both physiological and psychological relaxation due to its abstract nature, causing varied experiences. Additionally, cognitive load associated with the color gradient interface exhibits a significant correlation with breathing rate, attention, and attention stability. The need for sustained focus to comprehend the abstract changes in this interface enhances attention stability, which consequently leads to a higher cognitive load.

In terms of game experience, a sense of competence, immersion, tension, and challenge influence cognitive load, particularly mental and temporal load, subjective performance, and frustration. Higher competence and immersion reduce subjective cognitive load. However, tension and challenge are associated with increased cognitive load, particularly performance, effort, and frustration. Therefore, game design for relaxation training should enhance competence and immersion while reducing challenges and tension to lower cognitive load.

Mental and temporal demand significantly impact attention and breathing rate. Higher mental load decreases attention, while higher temporal demand increases breathing rate. Therefore, breathing guidance interfaces should minimize time pressure. Game-induced flow, tension, challenge, and negative affect impact various physiological and psychological relaxation indicators. Additionally, negative affect is significantly and positively correlated with average RMSSD, indicating that negative affect promotes physiological relaxation due to the boredom, distraction, and fatigue associated with reduced overall game stimulation. However, emotional responses themselves are quite complex, so future research could delve deeper into their impact on relaxation.

Limitations

This study focused on analyzing four specific guidance mechanisms. Additionally, we only considered the dependent variables of cognitive load, game experience, relaxation and attention, without evaluating the effectiveness of insomnia therapy. Therefore, the therapeutic effects on insomnia were not within the scope of this study. Therefore, in the future, diaphragmatic breathing games can be incorporated into the brief behavioral treatment for insomnia, with long-term observation and follow-up to understand whether gamified relaxation training can enhance the effectiveness of insomnia treatment.

Conclusion

In the design of diaphragmatic breathing guidance for insomnia patients, the study results indicate that the up/down interface is the most effective, as it results in lower cognitive load and higher relaxation. Both gaming experience and cognitive load significantly affect relaxation, with psychological and temporal demand having a notable impact on breathing rate. Positive and negative affect are critical factors influencing relaxation, with negative affect associated with higher relaxation effects. These findings offer valuable insights into the design of diaphragmatic breathing training, suggesting that appropriate guidance methods and gamified designs can enhance relaxation effects. Recommendations are made for the design of pre-sleep breathing guidance and relaxation training apps.

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Conflicts of Interest

None to declare.

Multimedia Appendix 1

Correlation Analysis Results of the four Interfaces.

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Supplementary Files

Multimedia Appendixes

Correlations among variables for four interfaces.
URL: http://asset.jmir.pub/assets/85b53c19784338d8b7af887bb62935d2.docx

CONSORT (or other) checklists

Pilot study.
URL: http://asset.jmir.pub/assets/932c3f5854202849bc8b0062ea689b5e.pdf