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Review

Practicing emotion-regulation through biofeedback on the decision-making performance in the context of serious games: A systematic review

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ABSTRACT

Evidence shows that emotions critically influence human decision-making. Therefore, emotion-regulation using biofeedback has been extensively investigated. Nevertheless, serious games have emerged as a valuable tool for such investigations set in the decision-making context. This review sets out to investigate the scientific evidence regarding the effects of practicing emotion-regulation through biofeedback on the decision-making performance in the context of serious games. A systematic search of five electronic databases (Scopus, Web of Science, IEEE, PubMed Central, Science Direct), followed by the author and snowballing investigation, was conducted from a publication's year of inception to October 2018. The search identified 16 randomized controlled experiment/quasi-experiment studies that quantitatively assessed the performance on decision-making tasks in serious games, involving students, military, and brain-injured participants. It was found that the participants who raised awareness of emotions and increased the skill of emotion-regulation were able to successfully regulate their arousal, which resulted in better decision performance, reaction time, and attention scores on the decision-making tasks. It is suggested that serious games provide an effective platform validated through the evaluative and playtesting studies, that supports the acquisition of the emotion-regulation skill through the direct (visual) and indirect (gameplay) biofeedback presentation on decision-making tasks.

1. Introduction

Biofeedback allows individuals to visualize specific physiological parameters to raise awareness and improve *emotion-regulation* (ER) so that the aversive behavior may be changed [1]. Unfortunately, these physiology visualizations are nonintuitive to many individuals. Compared to traditional approaches, *serious games* are interactive media which can provide a context for the biofeedback presentation and on-line perception of emotional responses, which are reflected on the changes in the individuals' physiology [2]. Such biofeedback methods provide a shortcut to raising awareness of internal bodily states and emotions, which have been found to critically influence human *decision-making* [3,4]. In the context of serious games, physiological sensors are used to monitor players' emotional states during gameplay, while the game mechanics are then adapted to reward the target behaviors [5]. Previous studies have shown that such 'serious game biofeedback' approach facilitates skill-acquisition and transfer [6]. Emotions and decision-making biases are even beyond conscious awareness , and it is therefore highly interesting to regulate such emotional dispositions [7,8]. Therefore, awareness of emotions is a necessary prerequisite to be equipped with the skills to decide whether it is better to follow an emotional response or not [9].

Emotion-regulation can help to mitigate emotion-related decision biases and eventually lead to a better decision performance. Emotion-regulation using biofeedback has been extensively investigated. Nevertheless, serious games have emerged as a valuable tool for such investigations set in the decision-making context [2]. This interactive approach to such an investigation is highly context-dependent, where ER skill-acquisition and transfer are 'maximized' when individuals are provided with engaging context-dependent serious games, which have emerged as a tool that fits this purpose [10]. Furthermore, they can parallel the qualities of the traditional approaches regarding beneficial effects on attention and ER, while providing valuable conditions to improve accessibility, for example by giving clear instructions and multisensory feedback [10].

Previously published reviews argue that the future investigation would benefit from a systematic investigation of experimental work [11], examining in detail which game features are most effective in promoting engagement and supporting skill-acquisition/transfer [12,13]. The investigated reviews argue that the research on serious games is already an established field of science, where decision-making questions are a burning issue. These reviews were exclusively concerned with individuals' affective experience and motivation in serious

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games [14]. Furthermore, previous reviews provide a useful overview of games research, but the escalating volume of such research suggests that it would be more useful for future literature reviews to focus on more specific issues [13], which we tend to follow in our review.

During compiling this manuscript, a relevant literature review was published in the field of ER and serious games [15]. In contrast to the presented work, the mentioned review focuses on the investigations regarding well-being, relaxation, and ER training in clinical interventions. It is structured around the overall amount and quality of serious games regarding their affective and modality focuses. Since the selected studies do not overlap between these two reviews, this gives evidence that each of them is focusing on a different aspect of ER is serious games.

We have conducted a systematic, structured literature review to identify and investigate all the reported studies and summarized the current state-of-the-art in the effects of practicing ER through biofeedback on the decision-making performance in the context of serious games. We named this context with the acronym BEDS further in the text. Surveying the previous reviews found that there was no structured literature review in the mentioned area.

2. Related work

The various overlapping concepts within the models of emotions and affect are translated through psychology to computer science, especially its determinants, measures and how these were related to ER. These various concepts make it difficult to develop valid measures and a common understanding of emotions and affect, especially in the context of decision-making in serious games. According to Russell, emotions can be classified by the independent components of arousal and valence. According to this circumplex model defined by these two components, arousal represents the excitement level whereas valence defines whether the current emotional state is positive or negative. Physiology allows us to extract and interpret both valence and arousal in relation to emotional stimuli [16–20]. Apart from the circumplex model, a discrete model of emotions takes into account the level of presence of basic emotions like happiness, sadness, engagement, anger, fear [21,22]. While emotions enable us to take advantageous decisions [23,24], there is a possibility that emotions also hinder advantageous decision-making, especially if they are not accurately processed and get 'out of control' [25–28]. Individuals can lose control over their actions under the influence of high arousal, which can significantly threaten rational cognition and decision-making [29,30]. Therefore, a need arose to raise awareness of emotional processes and how they can affect decision-making performance.

2.1. Decision-making

Currently, psychology sees decision-making as a dual-process framework which works in two fundamentally different ways depending on the context: the slow and analytical rational system; and the fast and intuitive experiential system [31]. Decision-making may require a delicate balance between the activation of one framework mechanism or the other, which may lead to reduced performance [30]. The affect heuristic states that human decision makers integrate context-specific affective feelings into perception and their decision-making process. Therefore the context of a task has been identified as an important factor of how affective stimuli are processed [32].

The somatic marker hypothesis concluded that emotional responses to information events seem to be both a source of biases, as well as an important mechanism for advantageous decision-making, where somatic markers beneficially guide our focus of attention. According to the theory, decisions are aided by emotions in the form of elicited bodily states during the deliberation of future consequences, which makes different options for advantageous or disadvantageous behavior [26,33]. Arousal, whether caused by positive or negative valence, may be equally (and some argue even more) important than valence for decision-making performance. It has been found that individuals aware of their emotional states avoid being overpowered by their emotions. These individuals need to develop skills to interpret and down-regulate those affective states of high arousal [34,8,35], which may result in enhanced decision-making performance [36].

2.2. Emotion-regulation

Evidence shows that ER contributes to an advantageous decision-making [8], where individuals with lower ER skills are prone to make disadvantageous decisions with undesirable consequences [37]. The evidence further shows a significant relationship among the effective ER, increased awareness of emotional states and a sophisticated skill in down-regulating high arousal [38]. As ER can be both consciously and unconsciously processed [39], increased emotional awareness is crucial for improving it [12]. Increasing awareness of emotional states can improve the conscious awareness of one's physiological processes – interoception [40]. This review argues that using ER in the BEDS context, one can practice the skill of down-regulating high stress and arousal to perform better on a decision-making task.

People tend to use one of the two broad ER strategies to deal with emerging emotions (i.e., cognitive reappraisal and suppression) while facing difficult and stressful tasks [41]. The authors state that while response-focused ER strategy is 'suppression,' where it aims at altering and controlling the experiential, behavioral, and physiological response when the emotion has already unfolded completely; antecedent 'cognitive reappraisal' ER strategy applies while the emotion has still not reached its peak while unfolding. Suppressors tend to constantly push down emotions, ignoring the fact that they exist and are continuously affecting them, where the degree of inhibitory control is negatively correlated with susceptibility to framing effects in a decision task [37]. The authors state that both ER strategies take up cognitive resources, but suppressing emotions generally takes up more cognitive resources in comparison to the reappraisal strategy when encountering undesired emotions. Hence, emotional suppression can eventually take up so many cognitive resources that it can reduce one's performance in decision-making tasks compared to the strategy of emotional reappraisal.

Self-regulation is a broader term which includes mental resilience through ER [42,43]. Emotional resilience (also referred to as mental resilience) is the capacity to withstand, cope or recover from stress and adversity [44,45].

2.3. Biofeedback

While contingent reinforcement of behavior through biofeedback has been a part of the investigations from the early start, it has not been thoroughly investigated [46]. In contrast to traditional biofeedback, Gilleade et al. [47] refine this definition of affective feedback by stating that the individuals may not be aware that physiological states are being assessed since the intent is to evaluate natural affective reactions [48]. The investigation of the effect of incentive upon *heart rate* (HR) acceleration and deceleration through biofeedback found that subjects in the incentive group (monetary reward) showed better HR control than those in the non-incentive group [49]. *Instrumental conditioning* (IC) is the process of rewarding and penalizing individuals' behavior based on their decision response, and it is the central mechanism in the acquisition of skills using biofeedback in serious games [50], as depicted in Fig. 1. More specifically, the concept where the target IC behavior eliminates the occurrence of an aversive stimulus which leads to the reinforcement of that behavior (skill-acquisition), is termed *negative reinforcement instrumental conditioning* (NR-IC). The somatic hypothesis and research in psychophysiology found that the experience of both emotions and stress are known to be accompanied by a physiological state of arousal [51], which in turn manifests in changes in physiology [52]. Biofeedback in the NR-IC context forces individuals to down-

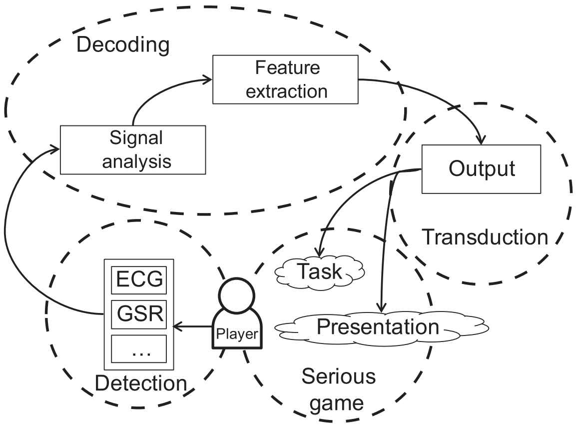

Fig. 1. The schematic overview of the biofeedback mechanism in serious games.

regulate their arousal levels (i.e., the instrumental response) to reduce game penalty (the aversive outcome) and progress in serious games [53]. Furthermore, NR-IC increases the likelihood that instrumental behavior will be repeated in the future indicating skill-transfer [54]. Whether the IC increases or decreases a behavior depends on both the nature of the outcome (i.e., aversive or appetitive) and whether the behavior produces or removes the outcome. Furthermore, reinforcements can be categorized as appetitive (pleasant outcome) and aversive (unpleasant outcome). Therefore, IC procedures can be classified into four categories [54]: *positive reinforcement* – when the target behavior produces an appetitive outcome, which leads to a reinforcement of that behavior; *punishment* – when the target behavior produces an aversive stimulus, which leads to a reduction in that behavior; *negative reinforcement* – when the target behavior eliminates an aversive stimulus, which leads to a reinforcement of that behavior; and *omission training* – when the target behavior eliminates an appetitive stimulus, which reduces that behavior.

Biofeedback in serious games can be viewed as a form of IC in which reinforcements (i.e., rewards or penalties in the game) are used to modify voluntary behaviors (e.g., increase or decrease breathing rate). In the NR-IC context, two types of reinforcement schedules (partial and continuous) were investigated to encourage players to slow down their breathing rates during gameplay, which reduces an aversive stimulus (i.e., random actions in the game) [6]. In fact, a long history of behavioral research shows that the reinforcement schedule can have a significant impact on skill-transfer, where NR-IC increases the likelihood that the instrumental behavior will be transferred [6].

2.4. Physiology

Heart-rate variability (HRV) is quantified by measuring the interval variability between successive heartbeats (*RR intervals*) in the *electrocardiogram* (ECG) signal [55]. Biofeedback may improve ER and cognitive functioning since evidence shows that HRV is associated with emotions, as suggested by the somatic hypothesis [51]. Previous investigations established a direct connection between the central nervous system and the *autonomic nervous system* (ANS), which is reflected in HRV [56], mediated through regulation of the vagus nerve [57,58].

Evidence shows that large amplitude modulation in HRV and *respiratory sinus arrhythmia* (RSA) are associated with certain specific executive functions: attention, flexibility of behavior and control of emotions [56]. RSA refers to the component of the change in RR intervals that is synchronized to the respiratory cycle [59]. Moreover, RSA may be a dominant component of the change in the RR interval when the individual's breathing is at an optimal frequency, which is referred to as 'resonant frequency' or 'coherence.' Maximal regulation occurs at a particular cardiovascular 'resonant frequency' of the baroreflex system correlated to HRV, typically 0.1 Hertz or a 10-second rhythm [60,59], and it has been found to reflect a balance between the two branches of the ANS, the sympathetic and parasympathetic nervous system. Deep breathing is a method to address the autonomic imbalance that arises from exposure to a stressor [61]. It recruits the parasympathetic branch of the nervous system and inhibits the sympathetic action, leading to a regulated state [6]. Regulating breathing rate towards this resonant frequency shifts the autonomic balance maximizing HRV and down-regulates high arousal [61,62]. Therefore, practicing RSA through the HRV biofeedback improves the skill-acquisition of ER by influencing physiology [63]. The goal of HRV biofeedback is to help individuals increase the relative amount of RSA in the HRV signal [55]. From both a psychological and physiological standpoint RSA has been shown to be most closely associated with self-regulation [56]. Previous investigations found that individuals with greater HRV had significantly more correct responses in a working memory test and in a 'Continuous Performance Test,' as well as faster reaction times [64]. RSA is also correlated with arousal values inferred from the HR [65].

Electrodermal activity (EDA) signal reflects changes in the sympathetic nervous system based on changes in the electrical skin conductance in response to external stimuli. Furthermore, EDA activity consists of two main components – tonic and phasic responses. Tonic skin conductance refers to the ongoing or baseline level of skin conductance in the absence of any particular discrete environmental events. Phasic skin conductance refers to the event-related changes, caused by a momentary increase in the skin conductance [48]. Inference of psychophysiological arousal based on EDA measurement has been proven to have a strong content validity [21,66].

2.5. Physiological and affective computing

Physiological computing allows for human physiology to be directly monitored and transformed into a control input for any technological system [66]. Such concept came out of the biofeedback approach that creates a closed-loop feedback design (see Fig. 1) to teach human participants the necessary skills for autonomic self-regulation. This design enabled the adaptive gaming technologies where the act of self-regulation is integrated directly into the gameplay [67]. The authors further state that biofeedback systems offer immediate reinforcement effects to facilitate 'training' or 'therapy' as a means to change physiological functioning and improve self-regulation skills. Biofeedback allows an individual to receive on-line feedback on their visceral processes which are usually almost unperceivable [68]. On another hand, affective computing draws methods from the original experiments on the psychophysiology of emotion, where psychophysiological changes are used for the detection of emotional categories (e.g., happiness, fear, disgust). Affective computing incorporates dynamic software systems sensing and adapting themselves on-line to the affective states based on psychophysiological measurements of the individual using it [69,70]. A shift towards more nuanced states that incorporate elements of both emotion and cognition enabled the use of psychophysiological activity from the player, which may be used to inform the response of interactive serious game applications. The potential of physiological computing to tailor each interaction to the specific responses from the individual player provided affective computing with the means to control the adaptive automation and present useful information to the player.

2.6. Serious games

Serious games can be understood as games that aim at purposes other than entertainment alone, and they are engaged in a 'serious' investigation of certain aspects of human endeavors [71]. Repeatable, highly engaging, and motivating serious games can result in improved training activities and have positive effects on the development of new knowledge and skills [72,73]. When decision performance may vary based on the individual's affective states, biofeedback-assisted tasks may achieve an increased decision-making performance. This has been supported through the previous investigations which have found that individuals can learn to attenuate the magnitude of their cardiovascular reactions to a variety of behavioral and physical stressors when provided with biofeedback-assisted training [74].

Biofeedback and other traditional methods to practice ER are hard to perceive by individuals,since they would need to invest a significant amount of time in training or need the supervision of a therapist, which can be time and cost prohibitive [10]. Validated biofeedback self-guided interventions (i.e., meditation, cognitive based therapy, and yoga) suffer from high dropout rates due to the unengaging nature of exercises and lack of motivation [45,75]. Furthermore, these techniques teach self-regulation in quiet, controlled settings, which may not generalize to the context of real-world stressors [76]. Traditional approaches for practicing ER fail mostly because of the limited capacity for self-monitoring [29]. As traditional approaches fail in improving ER skill-acquisition [34], serious games emerged as a new angle introducing technological methods to practicing ER, where meaningful biofeedback information communicates individuals' emotional states online [29].

Using biofeedback in serious games offers many advantages to practicing ER. In a stressful situation, the individual's focus is rarely on the physiological and psychological effects of stress. Therefore continuous information about the internal states while playing a highly captivating serious game would offer a possibility for players to become aware and actively use the appropriate coping strategy. Such stressful and highly captivating serious games are tailored to the players' individual skills through biofeedback by reducing the player capacity to play efficiently based on on-line physiological data. Contrary to the unengaging controlled environments which lack motivation and context [45,75,76], serious games can address these shortcomings by providing a context for the stressor and eliciting emotions including stress and arousal [44]. Biofeedback skill-acquisition is reinforced with a positive reward through the mechanism of operant conditioning. This is achieved through a provision of physiology information and reinforcement score presented after a successful regulation. Players have to make a decision to administer positive or negative rewards based on their success, where successful regulation is supported by the game score of the decision-making outcome.

2.7. Skill-transfer

For the basic principle of effective ER skill-transfer to work, an environment that induces stress and arousal is required, which may be difficult to recreate in didactic settings or role plays in a briefing room [77,78]. The neuroscience perspective might explain the skill-acquisition through using biofeedback in serious games, where performing goal-directed tasks (i.e., playing a serious game) leads to dopamines release in the striatum of the brain [79]. The authors found that there is a monotonic increase in striatal dopamine levels released during gameplay (compared to baseline) and that the effect was sustained after the gaming session ended. Such dopamine release is an indicator of memory storage events and attention [80]. Furthermore, it is also involved in learning stimuli or actions that predict rewarding or aversive outcomes. Therefore, serious games may facilitate improved awareness of arousal and effective skill-acquisition/transfer of ER [81,50,82].

3. Method

The selection of the publications was made according to an adapted 'The Quality of Reporting of Meta-analyses' (QUOROM) procedure [83].

3.1. Source selection

The preliminary search investigation had suggested that the relevant publications in the BEDS context are spread across multiple scientific journals and conferences. Therefore, a systematic search of five electronic databases (Scopus, Web of Science, IEEE, PubMed Central, Science Direct) was conducted. As there was no systematic review on this subject up till now, a timeframe limitation was excluded; therefore it was set from a publication's year of inception to the October 2018.

3.2. Search string

In order to identify the relevant papers for this literature review, we used individualized search strategies for the different databases, which included combinations of the following keywords: (game OR games OR gaming OR "serious play" OR "serious playing" OR task) AND (gam* OR play*) AND (emotion* OR affect* AND NOT (affects OR affecting OR affected)) AND (biofeedback OR neurofeedback OR ("neuro-feedback") OR ("neuro-biofeedback") OR neurobiofeedback) AND ((emotion* regulation) OR (modulat* emotion*))). This search identified articles related to serious games with biofeedback for practicing ER mentioned in the body of the paper, including the ones investigating the decision-making on tasks, which were identified later through the selection process. There may be a possibility that we are missing some papers mentioning physiology modalities directly or a specific affect or emotion, but without reference to ER or psychophysiological theories, those might not be relevant for our review. Only articles with *randomized controlled trials* (RCT) or quasi-experiment design with serious games investigating ER and decision-making performance published in refereed peer-reviewed journals and conferences were considered for review. Concepts such as emotions or affect were only included if the authors explicitly equated them with decision-making and ER. Informal literature surveys (e.g., theoretical papers) were excluded, as well as, the studies which did not contain measurable quantitative decision-making performance data and reported results on ER through biofeedback.

3.3. Search procedure

Fig. 2 shows the flow of studies throughout the review process, with the reasons for exclusion detailed at every step. In all five databases, the searches were combined to include all publications. The search resulted in a total of 265 publications. All of the collected abstracts were read and assessed based on their quality, making sure they truly cover the mentioned search terms. Discards were verified by a second rater, narrowing the main body of identified studies down to 36 quantitative studies. Two researchers took part in the identification, coding and quality assessment of the papers. The search was conducted by the first author, whereas both authors were involved in the review process, where Cohen Kappa statistic was derived from the same categorization using 20% of the entries to control for interrater effects. Interrater reliability scored Kappa $=.85$ ($p < .001$), 95% CI (.788,.067), which is higher than a Kappa value for almost perfect agreement of.8. The papers were scored on the concepts investigated by assigning a value of 0 to 4. Lastly, the publications included for analysis had to be original full papers and written in English. After a preliminary evaluation of the selected abstracts and references by the researchers to determine relevancy, full-length copies of the selected references were secured for the final evaluation. Again, the screening was done by the first author and an independent rater, while potential disagreements were resolved through iterative discussions.

Formulating a suitable search string is a very difficult task, as the terminology used is often not standardized and a large number of irrelevant papers will be found using broad search terms [84]. This approach may miss important research. Due to the small amount of the

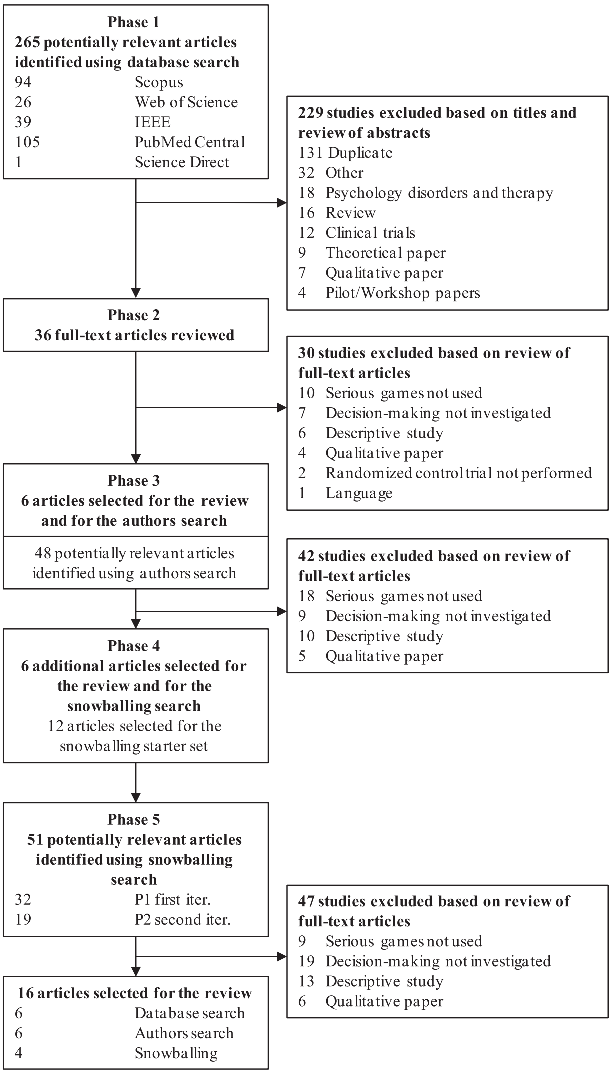

Fig. 2. The flow of studies throughout the review process.

initial research papers selected through the database search, the identified authors were checked for the new papers published additionally. Furthermore, backward and forward snowballing was conducted using Google Scholar in addition to the previously mentioned electronic databases, as outlined in the [84]. Research selected through the database and corresponding authors search has been included as the actual start set for the snowballing approach, and these were included in the systematic literature study.

The numbers of investigated papers through the snowballing method:

- Start set: 12 papers for the start set were included (6 papers selected from the database search and 6 papers selected from the authors search)
- Iteration 1: 32 candidates from backward and forward snowballing from start set and 4 papers were included
- Iteration 2: 19 candidates for inclusion were generated in backward/forward snowballing and no paper was included, and hence the snowballing ends.

3.4. *Coding of papers*

Iterative open coding was employed on the 16 selected papers, to identify different categories of research. These categories were then clustered according to the themes and axially coded for qualities such as methodology, results, aims, findings and so forth. Furthermore, the papers selected by the inclusion criteria were analyzed using the data extraction form that was developed by Connolly et al. [85], to find patterns concerning the main focus of the study.

3.5. *Quality assurance*

Papers were quality assessed according to the five criteria [85], where a formal quality score was completed by assigning a point for each criterion assessed: (1) quality of research design using RCT or quasi-experiment design; (2) appropriate methods and analysis; (3) generalizability of findings; (4) the relevance of the focus of the study (including serious games, decision-making, biofeedback, and ER) for addressing the research question and (5) trustworthiness of findings. Studies that scored 1–2 were regarded ‘low’ quality studies, while studies that scored 3–4 were classified as ‘relevant’ quality studies and were included in the review. Due to the contextual nature of biofeedback and ER, the generalizability of findings was jeopardized in all of the studies, rendering 4 as the maximal score through the quality assurance. The body of 36 identified studies from the database search, 48 identified studies from the authors search and 51 identified studies from the snowballing search (135 full-text articles in total) were assessed for quality, out of which 47 studies scored ‘low’, 72 studies scored ‘non-relevant’ and 16 studies selected for this review scored ‘relevant’.

4. Results

All selected studies presented in Table 1 were published in peer-reviewed journals and conferences which have been cited throughout the scientific community. Thus we can state that the research in the BEDS context has been recognized by the scientific community.

4.1. *Biofeedback*

Biofeedback in serious games is a broad subject, but it can be drilled down on a few components: psychophysiology, presentation, and other physiology measures.

4.1.1. *Psychophysiology*

ECG has been used in most of the investigated papers, measuring HR and HRV [55], where the latter has used the frequency domain measures of *the ratio of low and high-frequency powers* (LF/HF) and coherence ratio. Furthermore, respiration and EDA [48], also voice analysis [86] were used to recognize the emotional state of the players. Such extensive focus on HR and HRV in the BEDS context might have resulted from its strong correlation with arousal, and as a convenient physiological measure of ECG compared to the other physiological signals used to deliver biofeedback. Nevertheless, various signals have been used to deliver biofeedback therapies in serious games. The HR psychophysiology measure has also been correlated with the RSA [50] of the deep-breathing skills [6,81,82]. Through the BEDS context, evidence shows that biofeedback resulted in higher performance score on the tasks [81,82,29,87,77,22], compared to the control condition playing the game without biofeedback. It has been shown that resonant frequency of breathing influences decision-making performance and ER [6,81,50,82,55]. Furthermore, it has been found there was a significant increase in the mentioned ER physiology indices and a decrease in HR, for the treatment group [6,29,55,77,88–90]. Moreover, it has been found that using biofeedback resulted in higher attention scores [55], while higher HR arousal resulted in worse reaction time [91].

4.1.2. *Presentation*

Biofeedback can be presented in many ways but in the context of BEDS they all boil down to two methods: direct visual (overt) and indirect gameplay (covert) presentation. The direct overt presentation

Table 1
List of the selected papers for the review.

Nr.	Authors (Year)	Title	Design	Group Size	Number/Time of Trials
1	Parnandi and Gutierrez-Osuna (2018)	Partial Reinforcement in Game Biofeedback for Relaxation Training	RCT	24	17 min (3 × 5 min + break 2 min)
2	Zafar et al. (2018)	Gaming Away Stress: Using Biofeedback Games to Learn Paced Breathing	RCT	103	8 min
3	Parnandi and Gutierrez-Osuna (2017)	Visual Biofeedback and Game Adaptation in Relaxation Skill Transfer	RCT	24	30 min (6 × 5 min)
4	Zafar et al. (2017)	Playing With and Without Biofeedback	RCT	43	8 min
5	Lara-Alvarez et al. (2017)	Induction of Emotional States in Educational Video Games through a Fuzzy Control System	RCT	20	39 min (2 × 12 min + break 15 min)
6	Astor et al. (2013)	Integrating Biosignals into Information Systems: a NeuroIS Tool for Improving Emotion Regulation	RCT	104	25 min
7	Hilborn et al. (2013)	A Biofeedback Game for Training Arousal Regulation During a Stressful Task: The Space Investor	Quasi-Experimental	5	180 s
8	Bouchard et al. (2012)	Using Biofeedback while Immersed in a Stressful Videogame Increases the Effectiveness of Stress Management Skills in Soldiers	RCT	60	30 min
9	Jercic et al. (2012)	A Serious Game Using Physiological Interfaces for Emotion Regulation Training in the Context of Financial Decision-Making	Quasi-Experimental	6	25 min
10	Kuikkaniemi et al. (2010)	The Influence of Implicit and Explicit Biofeedback in First-Person Shooter Games	Within-Subjects	36	2000 s (10 × 200 s)
11	Liu et al. (2009)	Dynamic Difficulty Adjustment in Computer Games Through Real-Time Anxiety-Based Affective Feedback	Quasi-Experimental	15	24 min (12 × 2 min)
12	Goodie and Larkin (2006)	Transfer of Heart Rate Feedback Training to Reduce Heart Rate Response to Laboratory Tasks	RCT	14	2 h
13	Goodie and Larkin (2001)	Changes in Hemodynamic Response to Mental Stress With Heart Rate Feedback Training	RCT	46	35 min (5 × 6 min + break 5 min)
14	Larkin et al. (1992)	Effects of Feedback and Contingent Reinforcement in Reducing Heart Rate Response to Stress	RCT	48	33 min (5 × 3 × 2 min + break 3 min)
15	Larkin et al. (1990)	The Effect of Feedback-Assisted Reduction in Heart Rate Reactivity on Videogame Performance	RCT	67	33 min (5 × 3 × 2 min + break 3 min)
16	Larkin et al. (1989)	Heart Rate Feedback-Assisted Reduction in Cardiovascular Reactivity to a Videogame Challenge	RCT	20	28 min (4 × 6 min + break 4 min)

presents physiological information directly to the individual (e.g., via a visual display) about their emotional/physiological state using measurable presentation such as a bar [81,29,87,91]; a number [6,81,50,82]; a color of background and game artefacts [29,91,92,90]; sound [6,86]; and HRV signal [55]. Moreover, these investigations present the user with the target emotional/physiological state through visual indicators (e.g., message, arrow) [6,81,50,82], or through occluding the view [87,77]. The indirect covert presentation presents the physiological information indirectly through subtle changes in gameplay mechanics by changing game difficulty in proportion to the individual's stress levels, for reducing control of the game [6,81,50,82,86,29,87,91,48,22,92] and through manipulation of the game score [92]. The purpose of explicit biofeedback in the field of medicine is to make the individuals more aware of their bodily processes. This is achieved through displaying biofeedback information in a clear and easily perceivable way. Regarding implicit biofeedback, biosignals of the individuals modulate the system and its behavior, such that the individuals may not even become consciously aware of the feedback but still sense it on a subconscious level. Therefore, the individuals have direct and conscious control over the system in the case of explicit biofeedback, while the system is controlled indirectly through the affective signals in the case of implicit biofeedback [48]. Nevertheless, the separation between the explicit and implicit biofeedback is not perfect since the individuals may realize how the implicit biofeedback modulates the system and thereby gain control over it. In that case, separation becomes blurry, and the implicit biofeedback becomes explicit.

Regarding the BEDS context, direct visual presentation of biofeedback was successful in maintaining the target physiological state during the task [81,50,82]. On another hand, gameplay indirect biofeedback presentation resulted in deep-breathing skill-acquisition and transfer [81,50,82]. The players receiving overt and combined overt-covert biofeedback exhibited greater reductions in HR and better control to the serious game task, compared to the control group, with the combined ones having a significantly greater effect. This effect was also sustained for the post-training assessment task [6,92,74]. These claims might be important waypoints to using these different biofeedback presentations for different purposes, where the target behavior is optimally presented using visual presentation, while the skill-acquisition/transfer is optimally supported using the gameplay presentation of biofeedback. It has been found that each biofeedback presentation supports ER skill, while skill-acquisition of downregulating high level of arousal leads to a better decision-making performance [81,50,82,29,87,77,91], even in the case of brain injured individuals [55]. Players were found to perform worse in the overt explicit biofeedback presentation condition when they had to regulate arousal through EDA, in contrast to the covert implicit condition. Possibly controlling EDA signal is not as straightforward as the respiration for the biofeedback applications since the decision-making performance increased significantly in the overt explicit respiration condition [48].

There is evidence that using the combined biofeedback delivering visual and gameplay biofeedback simultaneously leads to performance increase on the decision-making task in serious games [55]. Furthermore, such combination of biofeedback presentation might support better skill-acquisition/transfer to other contexts than presenting each one individually (i.e., increased skill-acquisition/transfer of down-regulating high levels of HR arousal and deep breathing) [6,81,50,82,29,87,91,92,74].

4.1.3. Physiology measures

Measures employed in the selected studies were: HRV using time measure of *the fraction of consecutive interbeat intervals greater than 50 ms* (pNN50); EDA using skin conductance response which includes short-term phasic, emotional responses to specific stimuli [81,50,82]; and salivary cortisol, HR, blood pressure and RSA [81,50,82,77,92]. In addition to previously reported findings regarding the BEDS context, it has been found that ER achieved stress and arousal reduction using salivary cortisol, HRV-pNN50, EDA-skin conductance response and breathing rate [6,81,50,82,77]. The players receiving overt and combined overt-covert biofeedback exhibited a greater reduction in systolic blood pressure response to the serious game task, compared to the control group, with the combined one having a significantly greater effect [89,74]. This effect was also found in the post-training assessment task. On another hand, diastolic blood pressure response revealed no significant effects [89,92].

4.2. Tasks

The tasks used in the BEDS context can be divided into serious games, decision-making, attention investigation, and arousal validation. Regarding the validation of ER skill-transfer, the 'Halstead Category Test' is well-established and validated with reproducible reliability [93], and it has been found to have a significant association with problem-solving skills [94]. It has been used as a decision-making task to validate the increase in performance, while the 'Integrated Visual and Auditory Continuous Performance Test' has been used to validate the increase in attention [55]. Furthermore, performance on the Stroop color-word test and mental arithmetic tasks, King of Math and 'counting backward by N' have been used as well [81,50,82,88,89,92]. It has been found that lower HR responses were observed on the mental arithmetic challenge for the individuals who received the biofeedback treatment in serious games [88,89].

Performance results on the decision-making task using ER were obtained through a number of measurable outcomes, which can be divided into physiology measurements, questionnaires, and task performance. The performance was measured through biofeedback tasks in the decision-making serious games in all of the selected papers, using task performance score, response time and biofeedback performance score. On another hand, questionnaires measuring performance were: Behavior Rating Inventory of Executive Function (BRIEF-A-Informant), and The Trainees Evaluation Sheet [55,77]. External motivating rewards (i.e., monetary and movie tickets) were used to promote skill-transfer to real-world problems [29,55,87,91,22,88,89,92,74,90].

4.2.1. Serious games

Serious games aim to present a demanding and stressful task that can elicit sufficient arousal using time pressure, difficulty and fast-paced decisions in all of the selected papers. List of all the identified serious game and their methods of stress and arousal elicitation are shown in Table 2. In selected studies, behavior modulation has been controlled using two strategies: NR-IC and contingent reinforcement conditioning.

In the Frozen Bubble, players are presented with an arena containing a spatial arrangement of colored bubbles, and the goal is to clear the arena by placing a bubble next to two or more of the same color which makes them disappear. Through touch screen on an Android device, players control the orientation and firing of a small cannon that shoots bubbles of random color. The ceiling of the arena drops throughout the gameplay, and the game ends after the whole arena fills up. In the Left4Dead players have to collaborate to survive the zombie apocalypse. As part of a team, players have to exit a hideout and reach a rallying point on a farm while hordes of infected zombies are trying to kill them. Navigation is performed with keyboard keys and looking/firing with the mouse. In the Sno-Cat players control a vehicle up a simulated mountain, evading randomly appearing trees. The speed of the vehicle is fixed, while the movement is controlled by a joystick, and the brake is controlled by the fire button. The goal is to maximize the distance traveled, which is influenced by the amount of braking and crashes occurring during the gameplay. In the Space Investors players navigate a spaceship from one planet to another in space, while trying to avoid getting hit by the asteroids. Players cannot die in the game and only lose resources. The spaceship is automatically moving forward through space and is frequently approached by asteroids that must be shot down in order for the ship not to get hit. This is done with the mouse buttons, left for the primary weapon and right for the secondary. In the Auction Game players trade fictional 'goods' on the stock market. The players are presented with a task to calculate a mean value from three given price estimations, to be able to reach a buy or sell decision at the correct price. To make a decision, players have to use a mouse to click on the buy or sell button on the screen. In the Basic Math game, players must choose the correct mathematical operation by moving the falling object, obtaining points by dropping the object into the correct container before it reaches the bottom of the screen. Actions are performed with keyboard keys. In the Pong game players defend their side of the screen with a paddle changing size and speed, against an incoming ball that also changes speed and size. Movements are performed with keyboard keys. In the Emoshooter players have to aim at and shoot as many far-away enemies as possible, which attack the player in large formations. The goal is to keep the character unharmed by evading the bullets and avoiding falling into lava. Navigation is performed with

Table 2
List of the serious games and their arousal (stress) elicitation methods on a decision-making task, identified in this review. The games listed are: Frozen Bubble [6,81,50], Left4Dead [77], Sno-Cat [88,89,92,74,90], Space investors [87], Auction game [29,91], Basic Math [21], Pong [22], Emoshooter [48], Pacman Zen [81,82], Dodging Stress [81].

Serious game	Arousal	Time-pressure	Difficulty	Fast-paced	Outcomes	Biofeedback presentation	Regulation target	Type
Frozen Bubble	X	X			Skill-acquisition	HRV	Respiration	Mobile
Left4Dead	X		X		Decision-making	HR	Respiration	PC
Sno-Cat	X				Decision-making	HR	HR	PC
Space Investors	X		X		Decision-making	HR	HR	PC
Auction Game	X	X	X	X	Decision-making	HR	HR	PC
Basic Math		X	X	X	Decision-making	VOC		PC
Pong	X	X	X	X	Skill-acquisition	EDA	EDA	PC
Emoshooter	X	X	X	X	Decision-making	EDA	Respiration	PC
Pacman Zen	X	X			Skill-acquisition	HRV	Respiration	Mobile
Dodging Stress	X	X			Skill-acquisition	HRV	Respiration	Mobile

keyboard keys and looking/firing with the mouse. Pacman Zen is similar to the original Pac-Man game where players collect the white dots strewn across the maze. The difference in this version is that every ghost directly chases Pac-Man instead of enacting a more complex chasing behavior. When all the dots have been eaten, players advance to the next level. With each new level, the speed goes up, increasing the difficulty. Furthermore, if Pac-Man comes in contact with a ghost, a life is lost. There are three lives until the game ends. To navigate, players have to use a swiping motion on the mobile screen. In Dodging Stress, players guide the ball from one end of the screen to the other, avoiding obstacles in the way. The goal is to reach the target on the other end of the screen. The player must avoid hitting obstacles that move randomly around the playing field, or the game resets to the starting position. The game also features one continuous level where the game difficulty increases each time players reach the target. To navigate, players have to tilt the mobile device.

4.3. Emotion-regulation

Emotions have been investigated in the BEDS context for raising awareness as a prerequisite step for better ER and decision-making performance [29,91]. As somatic hypothesis promotes the embodiment, assessment, and regulation of emotions [55], most of the identified papers of the mentioned investigations were focused on how stress during a demanding decision-making task elicits a high level of arousal. It was found that the participants were aware of their arousal during the main biofeedback serious game task, which enabled them to avoid being overpowered by their emotions, and motivated them to develop skills to interpret and down-regulate those affective states of high arousal [91].

4.3.1. Relaxation

Regarding the BEDS context, evidence shows that there was an increase for the treatment group in ER for the downregulation of high arousal [6,81,50,82,29,55,77,92,90]. It has been found that using a correct reappraisal ER strategy leads to better performance in the BEDS context [29], but there has been no validation that down-regulating high stress and arousal leads to a better performance on the decision-making task, even though this has been a prevalent method in BEDS research. Nevertheless, all studies conclude that down-regulating high arousal, compared to the baseline condition, is beneficial for the performance on the decision-making task in serious games, where higher HRV resulted in better performance and attention scores [55].

Skill transfer of ER and down-regulation of high arousal to increase performance has been recognized as an important problem in the field, but it has been investigated only in eight of the identified studies context through tasks [6,81,50,82,88,89,92,90]. Findings from the post-treatment validation tasks show a successful ER skill-transfer where the decision-performance score was increased, while the respiration rate, HR and EDA responses decreased for the treatment in contrast to the control group [81,82]. These findings gave evidence that the partial reinforcement improves skill-transfer between the tasks [6].

4.4. Valence

Regarding the BEDS context, evidence shows that players were able to experience pleasant valence affect and reduce their unpleasant valence affect [86]. Results from these investigations indicated that positive affect could improve problem-solving and decision-making abilities [95]. Furthermore, it was found that the response time in a decision-making task is slower for players in low valence (unpleasant) affect compared to the other emotional states [86].

4.5. Healthcare

Certain health conditions have for a consequence reduced decision-making performance connected to the inability to process emotions correctly. The BEDS context has emerged as a valuable application of the mentioned concepts on a humanistic problem. It has been found that individuals with the ANS dysregulation (e.g., brain injury, post-traumatic stress disorder) have a limited possibility to modulate their HR, which in turn results in low amplitudes of the HRV. This problem has been traced to deficits in executive functioning, which is related to poor decision-making performance on the tasks [55,77]. There is an association between successful ER and HRV biofeedback, where even brain-injured individuals can acquire this skill and build mental resilience, but their executive functioning might not improve through this method [55]. On another hand, serious games with biofeedback provide a nonpharmacological means to reduce cardiovascular reactions to behavioral tasks, potentially reducing the risk of developing cardiovascular disease or hypertension [90].

4.6. Methodology

The approach taken in these studies was to administer ER training in the BEDS context and investigate the effects of ER using the same or side validation tasks. The proposed solutions in all of the selected studies were to relate if HR or EDA can be regulated through different biofeedback presentations (i.e., visual, gameplay and combined) to improve ER skill-acquisition/transfer and increase performance on decision-making tasks [50,77].

All of the selected studies evaluated the effectiveness of biofeedback serious games for ER skill-acquisition through a stressful decision-making task across varied application fields. Moreover, all investigated studies examined objective measures of player arousal, valence and behavior throughout the gameplay. The design adopted in the studies was related to the physiological outcomes related to the performance on the decision-making task. Furthermore, these studies used high-quality experimental designs being used to support the need for evidence from well-controlled studies where outcomes are relatively straightforward to measure. For the RCT studies ANOVA was used between the treatment and control conditions, while the quasi-experimental design employed a correlation analysis together with repeated-measures ANOVA. All studies reported recording a pre-treatment baseline, prior to the task training and treatment were administered.

5. Discussion

Regarding our key focus on the effects of rewarding and practicing ER through the BEDS context, following claims have been found in the investigated works. Participants can regulate their arousal measured with physiology (i.e., HRV, HR, salivary cortisol) through combined biofeedback (visual and gameplay) presentation training in the BEDS context [55,77]. Such individuals who raised awareness of emotions and increased the skill of ER were able to successfully regulate their arousal, which resulted in better performance, reaction time and attention scores on a decision-making task in serious games [6,81,50,82,29,87,55,91,77]. Nevertheless, the valence side of Russell's circumplex model of emotions [16] was underrepresented in the investigated works, correlating with positive as well as negative affective states which might be related to performance in decision-making.

Extensive ER and biofeedback training prior to the experiment with serious games is necessary to resolve the ambiguity where higher decision-making performance scores, compared to the control groups, were reported in some studies [29,87,77], while worse ones were reported in the others [6,92]. The control groups played an easier non-biofeedback version of the game in all of the experiments and showed a constant game score throughout. These versions of the serious games were without the (negative) effects of the biofeedback increasing the task difficulty. Extensive training should become a mandatory requirement to bring all the participants to the same skill level and normalize their performance results. Such training could be supported by other mindfulness approaches known to increase interoception (e.g., different forms of relaxation exercises, yoga, breathing patterns, or mindfulness courses), as a gap in knowledge has been identified of how these other mindfulness approaches affect performance in the BEDS context. This would enable researchers to make general claims of using biofeedback in serious games to support ER and increase performance on decision-making tasks. These suggestions could also save discarded datasets because of participants who were not able to follow the instructions on how to perform the experiment. The benefits of practicing ER are largely dose-dependent, which means that the individuals who consistently practice tend to benefit both in the short- and long-term, which is lacking in the current research investigations [12]. Therefore, such environments could be a valuable support for the users and contribute to long-term skill development of effective ER.

HR is probably a poor measure for a physiological assessment of arousal, as many controversial results regarding it were reported. Some studies reported a decrease in HR arousal in the BEDS context [29], while others reported an increase [77], and no significant change between groups [92]. This controversy is also related to the performance assessment on a decision-making task. Some studies reported that higher HR arousal results in lower performance [29,91], while others reported that lower HR arousal results in lower performance [6,50], and also no significant change between groups [92]. Poor selection of a biofeedback presentation through a scoring mechanism was a big factor in the discussion, where the biofeedback treatment group had worse decision-making performance, compared to the non-biofeedback control group. The scoring mechanism has not had a clean separation between the game performance and biofeedback performance score [88–90]. Therefore, the players were confused while observing that their HR biofeedback improved their game score, while at the same time they were not improving on their decision performance. The controversy regarding these studies claims that decision-making serious games in the affective computing field can induce sufficient arousal to participants, such that they can practice ER in such BEDS context and be correctly rewarded for it [29]. On the contrary, others claim that sufficient arousal was not achieved in such context [77]. The uncertainty to whether higher or lower arousal is correlated with better performance on the decision-making task in serious games might be due to lacking in methodology regarding the validation of serious games. The optimal level of stress and arousal for a given decision-making task depends on the context of the task and the individuals performing on it. Thus it cannot just be said that down-regulation will increase performance. Experiments need to build a player-centered design methodology and validate whether the decision-making tasks in serious games elicited sufficient levels of arousal [50,29,77,91]. Even more so, since arousal is correlated with the performance score through a bell-shaped curve of Yerkes-Dodson-Law, which states that there exists an optimal arousal level for high performance on the task [50,29,77,91]. Without this step, claims cannot be made as to how arousal affects performance on the decision-making task in serious-games. Contrary to HR, there is evidence that HRV and salivary cortisol might be more promising measures of arousal.

6. Limitations

This review summarizes the research on serious games in the BEDS context based on the search terms used within the databases included, without a time period limitation. Therefore, just like other reviews, it does not claim to be comprehensive. Only papers published in English that provided quantitative analysis with a controlled experimental design were considered. Specific focus on ER delivered through biofeedback in the stressful context of decision-making in serious games of this review was used, but the loss of data due to these criteria must be acknowledged. Due to the quantitative focus in the current review, only 16 papers were included, and it is possible that some high-quality qualitative studies were not considered which may inform the development of quantitative measures. Furthermore, research on serious games with biofeedback in other fields is available but was considered outside the scope of this review.

7. Future work

There is a need for involving the view on the ER on a decision-making task from the perspectives of neuroscience, psychophysiology, cognitive psychology which might have a different approach. These areas might give further answers to the cognitive functioning of ER with the biofeedback integration in decision-making serious game tasks, and neural pathway activation between different emotions.

Previous investigations already gave evidence that the ANS is responsible for the executive functioning and decision-making, but the identified investigations did not separate the individual ANS pathways (sympathetic and parasympathetic nervous systems) to tackle the effect of different emotions on performance on a decision-making task. Only arousal has been put into the context of sympathetic and parasympathetic nervous system activation [29,55]. Moreover, regarding biofeedback measurements, ECG was used to measure HR, HRV, and RSA [6,50,29,55,87,91,77,92]. All of these measures are related to the heart, but future should whiteness more diverse investigation of other biofeedback modalities necessary to map out the benefits of biofeedback on ER and decision-making, especially if we want to generalize the claims towards the nervous system, neurology, and psychophysiology.

8. Conclusion

The ideas in these selected investigations bring together biofeedback supporting ER skill on decision-making tasks for the novel applications providing evaluation and validation methods for designing serious game artifacts [29,87,91]. The authors tackled this ambiguity in the current research while providing the evidence for the efficiency of different biofeedback presentation modalities [50] and how ER skill can be acquired using biofeedback in serious games and transferred to another context through the use of contingent reinforcement [6,77,92]. Finally, these investigations gave evidence towards improving the lives of brain-injured individuals [55].

The question of whether biofeedback methods increase performance on the decision-making task by supporting ER in serious games, or by reduced arousal making the task easier, is a relevant issue. It was reported that without the proper calibration or normalization of biosignal data the biofeedback effects implemented in serious games would break the game balance [48]. Unfortunately, these investigations have an ambiguity regarding how arousal influences performance, even if increased performance was reported. More specifically, this ambiguity in the mechanism of biofeedback loop defines that difficulty in the serious games is endogenously connected to arousal, where individuals with higher arousal had a more difficult decision-making task which might have made them more aroused, and vice-versa. Especially since this ambiguity was reflected on the game score, which defines performance on the task. Compared to the control groups, the serious games were probably more difficult also for the individuals using biofeedback on the decision-making tasks, since the extensive ER training was missing and the biofeedback groups had to learn how to regulate HR, which might have increased arousal on the tasks. The discrepancy in decision-making performance results may be partially attributed to the length of HR biofeedback training provided in the selected studiesespecially since the evidence showed that with a sufficient training period, the discrepancy disappeared [74]. Control groups should be presented with decision-making tasks without biofeedback, to investigate if the participants used ER skills at all. To make stronger claims, it is also necessary to introduce a sham-biofeedback condition where the game performance score and difficulty are independent of biofeedback, without influencing one another. Moreover, the sham-biofeedback control group should be presented with false biofeedback or biofeedback not connected to the decision-making task, to untangle the biofeedback loop and investigate how emotions and ER affect the decision-making task performance. Otherwise, one group might have a lower performance just because it does not have the necessary information which affects the performance score, which makes it hard to compare results from the control and sham-biofeedback conditions against the treatment groups. Without standardizing and integrating sham-biofeedback and control conditions in the experiment design, as well as screening and validating that the participants practiced ER during the task, general conclusions cannot be drawn on how biofeedback supports ER and affects decision-making performance in general. Most of the investigated studies sport this limitation. Investigations in this area should untangle the biofeedback loop and remove the ambiguity that the task just got easier with reduced arousal, as was attempted in three of the selected investigations [29,91,74]. Control groups have been used in these investigations with: a more difficult gameplay [50], less difficult gameplay [29], no biofeedback or task presented [77] and without biofeedback on the task [6,81,82,29,22,88,89,92,74,90], compared to a treatment group. Similarly, sham-biofeedback groups have been used in these investigations with: biofeedback presented but not connected to the task [92], and biofeedback connected but not presented on the task [29].

Previous investigations found that the skill-transfer is highly contextual. The BEDS method should be applied to concrete research contexts which include the relevant ecology of the target audience and tasks resembling naturally-occurring stressors. This provides support for the serious games applicationsthat allow framing of a decision-making task in the relevant context. Investigations in the ER have used validation tasks to assess skill-transfer of individuals' abilities to down-regulate high arousal in the absence of biofeedback [81,82,88,89,92,74,90]. Through the investigated works, the ecological validity of participants has been used in the military context [77] and brain-injury context [55], while the rest of the studies have used student participants. Therefore, as the field moves forward, a relevant ecological valid cohort for the participants is necessary to investigate these effects in different contexts. These limitations make it hard to draw general conclusions outside of the presented context.

All of the identified investigations are not-generalizable, context-dependent, without proper disagreeing views being presented. Therefore, exactly these aspects should be the future direction in this area. These investigations provide evidence motivating the different biofeedback presentation modalities in the BEDS context [50,92]. Moreover, they give evidence regarding validation of sufficient arousal elicited which allows the suppression/reappraisal ER strategy to be used to increase performance on the decision-making task [29,87,91,77]. On another hand, they also raise future questions regarding the ambiguity of higher or lower arousal increasing decision-making performance through biofeedback presentation. Furthermore, they aim towards a more player-centered design of serious games, which motivates their use as a solution for the investigated scientific problems [29,87,91]. Furthermore, these investigations raise future questions regarding skill-transfer to different task contexts [6,81,50,82,87].

Nevertheless, the agreement between the investigated studies claims that the practice of ER using biofeedback improves performance on a decision-making task in serious games through regulating levels of physiological arousal, where combined biofeedback presentation (i.e., direct visual and indirect gameplay) supports such ER skill-acquisition and transfer, even in the case of brain injured individuals [6,81,50,82,29,55,87,77,91,92]. Furthermore, designed serious game artifacts have been validated through evaluative and playtesting studies as an effective platform for practicing ER skill-acquisition [29,87,91].

Practicing the skill of ER on decision-making in serious games can lead to better decision performance on the task, but careful consideration and standardization regarding methodological approach (i.e., a sham-biofeedback condition, control condition, ER pre-training, biofeedback measures, and presentation modalities) are needed to observe the benefits of such methods.

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