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Relaxation under High Cognitive Load: Do Deliberate Attempts Backfire

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Abstract. Ironic process theory proposes that deliberate attempts at mental control may become counterproductive when cognitive resources are taxed. The present study sought to replicate and extend Wegner, Broome and Blumberg's study of ironic effects in relaxation by examining whether cognitive load would moderate changes in physiological arousal during progressive muscle relaxation (PMR). Ten postgraduate students completed both no-PMR and PMR conditions while assigned to either a low- or high-cognitive-load group. Physiological arousal was assessed using galvanic skin response (GSR), with subjective relaxation also measured. The results showed that applying PMR significantly decreased GSR under both high and low cognitive loads (p = .006, p = .018). The interaction between cognitive load and deliberate relaxation, on the other hand, was also not significant (p = .128, BF_{10} = .733). Thus, the predicted ironic relaxation effect was not clearly reproduced. Given the small sample and fixed condition order, the findings should be interpreted as preliminary. The study highlights the need for larger, counterbalanced replications with sustained cognitive-load manipulations to clarify when deliberate attempts to relax may become counterproductive.

Keywords: Ironic process theory, Ironic effects, Mental control, Progressive muscle relaxation, Galvanic skin response

1. Introduction

University students routinely encounter substantial academic demands, including examinations, assignment deadlines, presentations and career-related pressures. The consequences of persistent and overwhelming stress can be concerning. Recent studies and a large-scale survey report have documented substantial mental health concerns among university students [1-3]. At the more severe end of the spectrum, unhandled stress can breed a devastating outcome: suicidal ideation. Recent studies regarding university students' suicidal ideation have suggested that a high proportion of participants endorsed active suicidal thoughts. Additionally, first-year university students were usually susceptible to suicidal ideation, and there was relatively high probability (approximately 1 in 5 students) that such ideation will persist in following years [4, 5].

A growing body of research indicates that relaxation-based approaches, including mindfulness, grounding, and progressive muscle relaxation (PMR), can reduce stress and anxiety among university students [6-8]. For example, a meta-analysis by Johnson et al. provided robust evidence

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that applying mindfulness training can effectively reduce stress and depressive symptoms among college undergraduates [7]. Likewise, Scott, Duncan and McCoy proposed that the five-sense grounding technique can significantly reduce test anxiety among nursing students [8]. Physically engaged techniques, on the other hand, can promote psychological well-being via somatic adjustment and relaxation. Implementing abbreviated progressive muscle relaxation (APMR) can help college students who experience high level of stress mitigate anxiety [9]. In a recent systematic review, PMR has been tested effective in alleviating stress, anxiety and depression [10].

Ironic process theory provides one account of why deliberate attempts at mental control may sometimes produce unintended outcomes [11]. According to the theory, intentional mental control involves two interacting processes: an intentional operating process and an automatic monitoring process. The operating process actively searches for thoughts, sensations, or actions that are consistent with the desired state, whereas the monitoring process scans for signs that the desired state has not yet been achieved. Importantly, the operating process requires cognitive resources, whereas the monitoring process is relatively automatic. If cognitive resources are depleted, perhaps due to distractions or stresses, the intentional operating process will therefore be hamstringed and more susceptible to failure contents that keep being triggered by the ironic monitoring process. As a result, the unwanted state may become increasingly accessible, potentially producing an outcome opposite to the individual's intention [11, 12].

Consistent with this account, ironic effects have been observed across several domains of intentional control. In motor performance, for instance, air-pistol shooters are more likely to hit the ironic zone, where is instructed to avoid on the target during the shooting task, under high pressure [13]. Elite dancers who were instructed to 'not wobble' were significantly less stable than those who were instructed to 'remain steady' under high cognitive load [14]. Ironic mental process also causes backfires when effort is applied to suppress negative emotions. Participants who were asked to suppress their distressing emotions while writing down stream-of-consciousness had negative mood scores that were significantly higher than those with no instructions [15]. Additionally, seeking fast asleep will paradoxically cause undesired wakefulness under high mental load [16]. These findings raise the possibility that deliberate attempts to relax may similarly become ineffective when cognitive resources are taxed.

Wegner, Broome and Blumberg provided an early experimental test of this possibility by examining whether cognitive load interfered with deliberate relaxation. Across two experiments, participants attempted to relax under conditions that varied in cognitive demand. Their findings provided suggestive evidence that deliberate relaxation under high cognitive load could be accompanied by greater physiological arousal, consistent with ironic process theory. However, evidence for the critical ironic effect was not unequivocal. In particular, participants' electrodermal level was elevated when PMR was instructed under high cognitive load. It was not significantly different from those who were not instructed to relax [12]. Therefore, the robustness of the effect remains important to evaluate through independent replication. The present study supplemented a permutation test and a Bayesian ANOVA to improve robustness in statistical analysis. The study also extends the paradigm to postgraduate students, providing a preliminary test of its generalisability to another university population.

The present study examined whether cognitive load moderated the effect of deliberate relaxation on physiological arousal among postgraduate students. A 2×2 mixed factorial design was applied for the study. Repeating/memorising a multiple-digit number has been proven effective in taxing mental capacity [12, 14]. Therefore, remembering a 9-digit non-repeat number was applied to manipulate cognitive load for the present study.

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Based on ironic process theory, we hypothesised that cognitive load would moderate the effect of deliberate relaxation on physiological arousal. Specifically, the reduction in physiological arousal associated with deliberate relaxation was expected to be attenuated or potentially reversed under high cognitive load relative to low cognitive load.

2. Method

2.1. Participants

Twelve participants were recruited from the University of Edinburgh for the experiment (8 females, 4 males). Participants range from 18 to 45 years. Eligibility was restricted to students who were currently enrolled in a postgraduate program.

The method of recruitment was via e-mail invitation. One participant withdrew before completing the experiment because of a scheduling conflict. The GSR recording of one participant, although completed the procedure, exceeded the pre-set sampling range during the 5-min experimental section. This dataset, therefore, was unusable and did not proceed with data analysis. The final analytic sample therefore consisted of 10 participants. All included participants completed the experimental procedure without reporting difficulties. Upon completion, each participant had an opportunity to win a £20 prize through a prize draw. Ethical approval for the study was granted by the appropriate ethics committee at the University of Edinburgh.

2.2. Design

The study employed a 2×2 mixed factorial design. Cognitive load (low vs. high) was manipulated between participants, whereas relaxation instruction (no PMR vs. PMR) was manipulated within participants. Participants were randomly assigned to either the low- or high-cognitive-load condition and remained in the same cognitive-load condition across both relaxation conditions. The independent variable of this study was PMR implementation. The dependent variable was arousal state. And the moderating variable was cognitive load. The experiment was separated into two parts: implement PMR or not implement PMR. The cognitive load was manipulated by recalling one-digit number (low cognitive load) or nine-digit non-repeat number (high cognitive load). Participants were asked to write down the given number after each experimental part for recalling error check.

The arousal state was measured by galvanic skin response (GSR). GSR is a bioindicator that reflects skin conductivity. The bodily reaction to stimuli causes changes in skin conductivity. The higher the reading, the more aroused the participant was. The unit of GSR readings was micro-Siemens. Three specialised apparatuses were used in the experiment to record GSR data. A laptop with specialist software was applied to view, record and export raw GSR data. The manufacture was HP; and the serial number was HSS-EDUC-0577. A PowerLab 8/35, model: PL3508; and a GSR Amplifier, model: FE116 both manufactured by ADInstruments were used to monitor and digitalise GSR data. The serial number for PowerLab was 3508-2663, and for GSR Amplifier was FE116-1359. A 5-point Likert subjective feeling scale that was used in Wegner's study was applied in the present study to reflect subjective relaxation state. It contained 15 adjectives: *relaxed*, *calm*, *sleepy*, *restless*, *bored*, *agitated*, *tranquil*, *happy*, *placid*, *composed*, *tired*, *anxious*, *tense*, *fidgety* and *upset*.

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2.3. Procedure

In the first part, the procedure began with introduction of apparatuses, instruments and the procedure to participants. And participant information sheet and consent form were presented and explained to participants. The examiner then set up the equipment after participants signed the consent.

Participants were asked to take 5 minutes to familiarise the experiment environment, 1 minute to fill the subjective feeling scale, and 1 minute to rest still. Then the examiner took 2 minutes to instruct participants not to relax (to create no PMR condition). In the following 5-minute experimental part, participants were asked to remember either a one-digit number (to create low cognitive load) or a non-repeating nine-digit non-repeat number (to create high cognitive load). Meanwhile, the examiner asked participant to follow the given instructions while remembering the given numbers. Participants were told that the number is important to the study, and they should do their best to memorise it. Finally, participants were asked to recall and write down the given number and complete another subjective feeling scale. The second part was almost identical to the first part, except for two things: skipping the opening introduction, implementation of PMR.

There could be a possibility that participants received the PMR instruction in the first part and applied it in the second part, consciously or unconsciously. In order to remove this residual effect, the within-group experimental order was not counter-balanced.

3. Results

Participants completed 2 parts in their experimental procedure, and the GSR data was recorded before and during the experiment. Each participant therefore had 4 sets of GSR data: baseline capture and experiment capture in no effort (no PMR) and deliberate effort (PMR) conditions. By subtracting baseline GSR from experimental GSR, 2 GSR elevation scores were obtained for each participant.

A repeated measures ANOVA was performed to examine the difference between each GSR elevation score. Partially contrary to proposed hypothesis, a significant decrease in GSR elevation was observed after implementation of PMR under high cognitive load (F (1, 4) = 29.36, p = .006, η_p^2 = 0.88, *95% CI* [1.43, 4.44]). A significant decrease in GSR elevation, as hypothesised, was observed after PMR was instructed to participants under low cognitive load (F (1, 4) = 15.17, p = .018, η_p^2 = 0.79, *95%CI* [0.50, 2.98]). In terms of main effect, the analysis revealed that implementing PMR significantly decreased GSR elevation (F (1, 8) = 44.33, p < .001, η_p^2 = 0.85, *95% CI*[1.53, 3.15]). The interaction between cognitive load and deliberate relaxation was not statistically significant (F (1, 8) = 2.89, p = .128, η_p^2 = 0.27). Numerically the decrease in GSR was greater under high mental load (ΔM = -2.93) than under low mental load (ΔM = -1.74).

Participants were asked to fill out the subjective relaxation scale 4 times in the entire experimental procedure: two times before the manipulation and two times after the manipulation. A post-post comparison was performed to check the effectiveness of applying PMR. Under low cognitive load, there were 80% of participants (N = 4) who felt more relaxed and calmer. Meanwhile, 60% of participants (N = 3) felt less sleepy and tense after PMR was instructed to them. This suggested that subjectively participants felt more relaxed after the implementation of PMR. Under high cognitive load, however, 80% of participants (N = 4) felt more relaxed, tranquil, placid, composed, calmer, and less restless and anxious. Sixty percent of participants (N = 3) feel sleepier and less agitated, tired, tense and fidgety.

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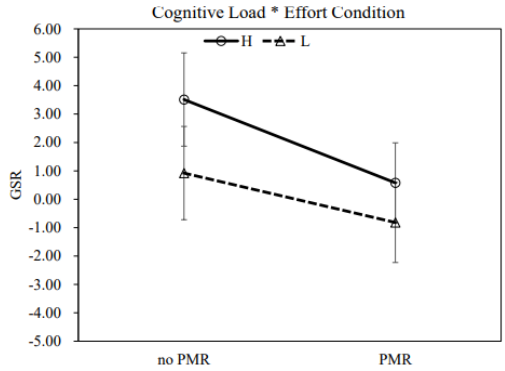


Figure 1. The interaction effects: cognitive load × effort condition. Note: error bar stands for Std. error

An exact two-sided permutation test was performed to examine whether the PMR effect differed between the high- and low-cognitive-load groups. The PMR effect was obtained by subtracting GSR elevation in no-PMR condition from GSR elevation in PMR condition. Numerically, the PMR effect was greater under high cognitive load (M = -2.93) than under low cognitive load (M = -1.74). The mean difference was -1.19, which did not reach statistical significance (p = .143). This result supported results from the repeated measures ANOVA.

Bayesian repeated-measures ANOVA was also conducted. The Bayesian analysis did not provide compelling evidence for the interaction between cognitive load and relaxation condition.

4. Discussion

The present study sought to replicate and extend Wegner et al.'s study of ironic effects in relaxation by examining whether cognitive load would moderate the effect of deliberate relaxation on physiological arousal. Contrary to the proposed hypothesis, we found that applying PMR reduced GSR under both low and high cognitive load. There was no sufficient evidence to support that cognitive load moderated the relationship between applying PMR and physiological arousal state. According to ironic process theory, intentionally applying PMR should paradoxically elevate the GSR under high cognitive load. The present findings, however, do not show such a phenomenon. There are several possible explanations.

First, the possibility of observing ironic effects is less general and more context-dependent than expected. Ironic effects may be more likely in the contexts of thoughts suppression and movement control [17-19]. These contexts share a common point: the goal to reach desired control is relatively clear and identifiable. The underlying mechanism could be interpreted by the notion of conscious monitoring process. Individuals generally know what thoughts they should avoid having while suppressing them, and what kinetic errors they should avoid in order to reach certain movement control. In these cases, the unconscious monitoring process is more likely to be brought to consciousness. Since its function is to keep searching for those unwanted outcomes. The conscious monitoring process in turn increases the accessibility of unwanted outcomes and then could overwhelm mental capacity and keep activating the operating process, consequently, incurs ironic effects [11]. That said, ironic effects possibly are sensitive to goal-focused situations.

In smoking behaviour, for example, participants who suppressed the thought of smoking for a week significantly backfired on cigarette intake than those who were thinking about smoking freely in the following week [20]. Similarly, the occurrence of ironic effects depends on what the goal is in motor tasks. A study of baseball pitching demonstrated that the change of goals altered the

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occurrence of ironic effects. When the goal was to hit the targeted zone as accurately as possible, ironic effects occurred in both hitting counts and skill execution, meaning less hits in targeted zone and distorted pitching skill. When the goal was to hit a targeted zone while avoiding an ironic zone, ironic effects occurred in only hitting counts [21]. This might be indicative that ironic effects favor goal-focused contexts.

A related possibility concerns the distinction between goal-focused and procedure-focused regulation. Relaxation may be a particularly complex context in which to observe ironic effects because successful relaxation often involves reducing goal-directed and analytical activity rather than intensifying it [22]. Many relaxation techniques align with this principle. For instance, mindfulness techniques help users channel their attention to the moment-to-moment present, and provide an accepting, nonjudgmental method to observe the present [23]. Similarly, progressive muscle relaxation, as used in the present study, directs attention towards immediate bodily sensations associated with muscular tension and release [24]. These structured relaxation instructions may channel attention to specific actions rather than continuous monitoring of whether the relaxed state is reached. Thus, ironic effects may depend partly on whether regulation is primarily goal-focused or procedure-focused.

A second explanation concerns cognitive-load manipulation. The present study applied a task of remembering a 9-digit non-repeat number to create a high cognitive load. In the high cognitive load, there was one participant who wrote down a wrong number while not giving PMR instruction. However, the recalling error rate increased to 60% (N = 3) while applying PMR. Additionally, participants under high cognitive load reportedly memorised the numbers relatively quickly. The task difficulty, therefore, does not establish how cognitive demands changed over the experimental procedure. Both raised the possibility that the task did not continuously tax participants' cognitive resources. If remembering numbers cannot keep distracting relaxation, ironic effects are less likely to occur [11]. As a result, there was a decrease presented in GSR elevation and an increase presented in recalling error rate. Because cognitive demand was not assessed continuously during the experiment, the present study cannot determine whether the manipulation produced a sufficiently strong and sustained load throughout the relaxation task.

4.1. Limitations and future research

Several limitations should be acknowledged. One of the limitations is the relatively small sample size. Only 10 participants completed the experiment. It suggested that the present study had limited statistical power to examine the hypothesised interaction between the cognitive load and deliberate relaxation. As presented in Figure 1, the within group error is relatively large. The individual difference could reduce the accuracy and stability of the estimated effects. Meanwhile, the non-significant interaction in the present study should not be interpreted as evidence for the absence of an ironic effect. The Type II error is still probable that ironic effects could exist yet have not been detected. The present study could not determine whether ironic effects were less likely in relaxation or limited statistical power blocked the observation. In this case, future studies should stress a larger sample size.

Second, as discussed in the previous part, the ironic effects are inclined to goal-focused context rather than procedure-focused context. However, the present study does not directly assess the attentional focus. Therefore, such difference remains theoretical rather than actually examined. For future studies, a valuable direction could be investigating whether ironic process theory functions differently in the goal-focused context and procedure-focused context. Most studies tested ironic process theory within contexts that require mental control, such as motor performance, attention

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focusing, thought suppression and relaxation. Between-context comparison currently is under explored. Studies that stress contextual differences of ironic process theory with clear methods to assess attentional focus could be valuable for furthering the understanding of this theory.

Third, measures of the present study are not elaborate. Although subjective relaxation ratings were collected, they were not analysed as a validated overall relaxation score, limiting direct comparison between physiological and subjective relaxation. Future studies should incorporate validated subjective relaxation measures alongside physiological indicators and directly examine their correspondence. There is a possibility that participants with relatively low GSR readings still feel psychologically aroused. Likewise, the present study cannot ensure that participants were focusing on the cognitive task through the experiment nor have the subjective measure to check if the cognitive resources were continuously taxed. The sole physiological indicator also limits the analytical robustness. For future studies, subjective indicators should be added in the experiment design to cross check with objective measures. Additionally, extra physiological indicators, such as salivary cortisol, are also beneficial to produce a robust analytical result. By introducing these measures into the analysis, a more elaborate picture could be presented.

Finally, the effectiveness of cognitive-load manipulation remained vague. Remembering a 9-digit non-repeat number is an economic and accessible method to tax cognitive resources. However, no consequences for wrong recalling, like the present study, could alleviate the stress to some extent. Additionally, the overall difficulty of this task is mediocre, especially given that the experimental duration was 5 minutes. For future studies, therefore, if researchers are set on applying this cognitive task, there should be some consequences for incorrect recalling. For example, some incentives, monetary maybe, should be linked to the outcome of the task so that participants can endeavor more rather than make some cursory attempts. Shortening the experimental duration could be another improvement. Better still, a more complex cognitive task, such as an IQ quiz, should be considered as proper replacement for cognitive-load manipulation.

5. Conclusion

According to Wegner, Broome and Blumberg's study of ironic effects in relaxation, we examined whether cognitive load moderates the effect of relaxation on physiological arousal. The present study did not clearly reproduce the ironic relaxation effect predicted by ironic process theory. These findings raise the possibility that ironic effects in relaxation may be context dependent than expected, potentially depending on the nature of the control goal, attentional focus, and monitoring processes involved. Future research that directly manipulates the nature of attentional focus while employing sustained cognitive-load tasks and stronger experimental controls may help clarify when deliberate attempts to relax become counterproductive.

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