Exposure to Progressive Muscle Relaxation leads to Enhanced Performance on Derived Relational Responding tasks.

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SUGGESTED RUNNING HEAD: PMR and Derived Relational Responding

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Abstract

Previous research has demonstrated that sleep significantly enhances the emergence of two- but not one-node derived relations following a 12-hour period. The present study investigated whether a brief 11-minute Progressive Muscle Relaxation (PMR) intervention would effect a similar enhancement in derived relational responding performance. Thirty-five participants were exposed to matching-to-sample training to establish stable baseline relations, from which two-node derived equivalence relations were predicted. Participants were then randomly assigned to either a PMR group or one of two control groups; Simple or Complex Discrimination task, followed by an equivalence test. In contrast to the sleep study, but in line with experimental predictions, exposure to PMR resulted in significantly more accurate responses for both one- and two-node derived relations. The immediate and significant effects on derived relational responding performance offer support for the role of brief relaxation or non-directed attention in improving cognitive performance.

Keywords: Derived relational responding, relaxation, meditation, cognition, stimulus equivalence.

Interest in the beneficial effects of meditation training in a wide variety of psychological contexts has grown rapidly in recent years (Brown, Ryan, & Cresswell, 2007; Carlson & Hoyle, 1993; Feldman, Greeson, & Senville, 2010). Although there are a variety of meditation techniques, for example, Transcendental Meditation (TM; Kabat-Zinn, 1994) and Progressive Muscle Relaxation (PMR; Jacobson, 1938), the outcome is generally a relaxed state and a passive accepting frame of mind in other words, a 'relaxation response' (Benson, 1975).

Conceptually, according to Benson (1975), this relaxation response is an inducible physiological state of quietude purported to train the capacity to attend more precisely to environmental events. During relaxation training meditators are taught to acknowledge the distracting discursive thoughts that inevitably intrude, and non-judgmentally return their attention back to their breathing (Wallace, 2006). With increased experience meditators report fewer intrusions of irrelevant thought (Feldman, et al., 2010; Kabat-Zinn, 1994). Relaxation is the antithesis of a general arousal or stress response (Benson, et al., 2000) and is essentially a wakeful hypometabolic state (Wallace, Benson, & Wilson, 1971).

Irrespective of the type of relaxation technique employed the effects are quite similar in terms of their stress reducing properties (Brown et al., 2007; Orme-Johnson, 2001; Rausch, Gaumling, & Auerbach, 2006; Travis, et al., 2009) and benefits to mood and cognition (Galvin, Benson, Deckro, Friccione, & Dusek, 2006; Miller, Fletcher, & Kabat-Zinn, 1995; Nava, Landau, Brody, Linder, & Schächinger, 2004). Indeed, in the cognitive domain relaxation training has resulted in significant improvements in attention (Galvin, et al., 2006; Grosschalk & Greg, 1996), visuospatial processing (Kozhevnikov, Louchakova, Josipovic, & Motes, 2009), and memory capacity (Subramanya & Telles, 2009; Yesavahe, 1984). Furthermore, relaxation techniques have facilitated significant increases in multiple measures of intelligence (Cranson, et al., 1991), greater flexibility in concept learning (Dillbeck, 1982;

Grosschalk & Greg, 1996), along with improved problem solving ability across age groups from young children to the elderly (Krampen, 1997).

It must be acknowledged that the majority of the studies demonstrating improvement in cognitive performance (Cahn & Polich, 2006) and mood (Davidson, et al., 2003) involve extensive, long-term relaxation training. However, there is a growing body of evidence in support of brief relaxation training. For example, Tang et al. (2007) reported that five days of Integrative Body Mind Training improved mood and cognition. More recently, Zeidan, Johnson, Diamond, David, and Goolkasian (2010) reported improvements in mood, verbal fluency, visual coding, and working memory following four days of brief 20-minute meditation training. Moreover, some studies have shown that considerable cognitive benefits can be achieved following a single relaxation session. Indeed, Nava et al. (2004) demonstrated enhanced long term memory retention performance following a single 12-minute relaxation session while Hudetz, Hudetz and Klayman (2000) showed enhanced working memory performance following 10 minutes of guided imagery.

It has been extensively posited that such cognitive enhancements are also the function of sleep (Hobson, 2005; Pegneux, Laureys, Delbeuck, & Maquet, 2001; Stickgold & Walker, 2005; Wagner, Gais, Haider, Verlerger, & Born, 2004) which is a hypometabolic state similar to relaxation. Sleep is characterised by some of the same metabolic and physiological changes observed in relaxation states, for example, decreases in heart rate, blood pressure, respiration and muscle tension and in the reduction of oxidative stress burden induced during periods of wakefulness and learning (Brown & Naidoo, 2010; Tononi & Cirelli, 2006). Furthermore, post-sleep enhancements on cognitive performance are well evidenced in the literature and are often theorised from a neurocognitive perspective to be the result of memory consolidation during sleep (e.g., Born, Rasch, & Gais, 2006; Diekelmann & Born, 2010; Stickgold, 2005, 2009). Memory consolidation has been correlated with the proposed strengthening of inter-cortical connections and increases in cortical thickness and plastic changes in the brain that occur during sleep (Born, et al., 2006; Kurth, et al., 2010; McClelland, McNaughton, O'Reilly, & Randall, 1996, Tononi & Cirelli, 2006). While an in-depth discussion of the effects of neurological changes in the structure of the brain is beyond the scope of the current paper, tentative evidence is beginning to emerge that suggests that extensive relaxation training results in similar structural changes in the brain as does sleep, in terms of increased cortical thickness and grey matter volume (Davidson, et al., 2003; Luders, Toga, Lepore, Narr, & Gaser, 2009; Lutz, Greischar, Rawlings, Richard, & Davidson, 2004; Newberg & Iversen, 2003).

Both relaxation and sleep are, therefore, similar in terms of physiological and metabolic changes (Benson, et al., 2000), benefit cognition (Stickgold, 2009), and are associated with structural changes in the brain (Kurth, et al., 2010; Luders, et al., 2009). Reductions in stress levels are also intrinsic to both sleep and relaxation states (Brown & Naidoo, 2010; Rausch, et al., 2006). There appears to be some debate as to the unique contributions of relaxation and sleep in terms of their beneficial effects on cognitive processes such as attention, perception, memory, and concept formation (Cranson, et al., 1991; Diekelmann & Born, 2010; Ellenbogen, Hu, Payne, Titone, & Walker, 2007; Ellenbogen, Hulbert, Jiang, & Stickgold, 2009; Krampen, 1997; 2010), as it is difficult to separately tease out the contribution to cognition of the stress reduction component inherent to both sleep and relaxation. It is conceivable that the cognitive benefits observed post-sleep may not be unique to the sleep state per se but may instead result from the stress reduction common to both sleep and relaxation.

The current study sought to address this knowledge gap with regard to the unique contributions of relaxation to cognitive enhancement. This study builds upon previous meditation research by examining the effects of brief relaxation training on cognitive performance, but specifically in relation to a cognitive task of great interest to experimental analysts of behavior. Specifically, the current study will examine the effects of a brief relaxation intervention on the formation of derived equivalence relations. This particular task is of interest because many behavioral psychologists take the position that the derivation of relations between stimuli underpins many aspects of complex human language and cognition (e.g., Relational Frame Theory; RFT; Hayes, Barnes-Holmes, & Roche, 2001).

Derived relational responding phenomena such as stimulus equivalence, describe the emergence of accurate responding to untrained and non-reinforced stimulus-stimulus relations. Typically, in a study on stimulus equivalence, a series of conditional discriminations involving arbitrary, physically dissimilar stimuli are presented in a match-to-sample (MTS) format. For instance, in the presence of sample stimulus A, selecting comparison B is reinforced (i.e., A-B) and on other trials selecting comparison C in the presence of sample A is reinforced (i.e., A-C). Following this training history, if the relations B-A, C-A (i.e., symmetry), B-C and C-B (i.e., combined symmetry and transitivity) emerge in the absence of any further training, the stimuli are said to have formed equivalence relations (Sidman, 1994) or to participate in a relational frame of co-ordination (Hayes et al., 2001).

Much recent research on stimulus equivalence relations has focused on how the formation of equivalence classes may be enhanced by the inclusion of meaningful stimuli in the trained baseline relations (e.g., Fields, Arntzen, Nartey, & Eilifsen, 2012; Arntzen, Nartey, & Fields, 2014) or manipulation of the training structures designed to establish such classes (e.g., Arntzen, Grondahl, & Eilifsen, 2010; Grisante, Galesi, Sabino, Debert, Arntzen, & McIlvane, 2013). For example, Arntzen et al. (2014) found that the enhancement effects in deriving stimulus relations by including a meaningful stimulus is quite context specific in that the position of the inclusion of the of meaningful stimulus is important as participants formed equivalence classes more readily when the meaningful stimulus was included in the first baseline trained relation (A-B) rather than in the final trained relation (D-E) in subsequent testing for the emergence of a five-member three-node equivalence class (i.e., A-B-C-D-E). Thus, while that strand of research focuses on enhancing derived relational responding by manipulation of stimulus content and training structure, the present study aims to enhance derived relational responding by manipulation of context in which such stimulus relations are established and emerge.

The present research also builds on the work of Ellenbogen et al. (2007), who found that sleep increased participants’ ability to derive complex transitively inferred relations between stimuli separated by two nodes from each other in a series of premise pairs (e.g., derived A>D, given A>B, B>C, C>D, D>E), but not stimuli separated by one node only (e.g., A>C). Thus, if brief relaxation training can be shown to improve cognitive performance, operationalized here as derived relational responding, it may be the case that it is the relaxation component of sleep that most likely contributes to the cognitive improvements widely observed following a period of sleep.

In the present study participants were randomly assigned to three groups, exposed to MTS training, and subsequently exposed to one of three different experimental conditions. Conditions 1 and 2 comprised a Simple and Complex Discrimination task, respectively, which were designed to inhibit relaxation and prevent rehearsal of trained baseline relations, thus, acting as control interventions. Condition 3 involved exposure to an 11-minute PMR intervention delivered via audio cd. Following the interventions, a MTS testing task probed for the emergence of equivalence relations.

Based on previous research (Tang, et al., 2007; Zeidan, et al., 2010) it was predicted that exposure to brief PMR training, when compared to the two groups that performed a discrimination task, would enhance cognitive performance as measured by derived relational response fluency. This design also allowed for an examination of the relative benefits of the PMR intervention on one versus two node derived relations.

Method

Participants

Fifty participants were recruited via personal contacts and advertisements offering a potential prize of 30 euro placed on campus notice-boards at the National University of Ireland, Maynooth. Participants comprised both undergraduate students and university graduates engaged in full-time employment. Overall, participants in each condition were roughly matched for age, educational status and socio-economic background and had normal or corrected-to-normal vision. No participant had prior knowledge or experience with stimulus equivalence research. Fifteen participants were eliminated from the study due to their performance on the MTS training or the baseline test phase. Of the 35 remaining participants, 18 were female and 17 were male, with an age range of 18-49 years (M = 24.09; SD = 8.29). Informed consent was obtained from all participants, with all procedures approved according to the National University of Ireland Maynooth Research Ethics policy.

Apparatus/Materials

Participants completed the experiment individually, seated at a table facing an Apple e-Mac© with an 800 x 600 pixel screen and a mouse. Stimulus presentation and response recording were controlled by the software application PsyScope version B55 (Cohen, Mac Whiney, Flatt, & Provost, 1993). Stimuli and feedback were displayed on screen using Times New Roman 24-point font on a white background. Stimuli were displayed in black and feedback in red characters. Eight nonsense syllables, CUG, PAF, VEK, JOM, ZID, KER, LEF and MAU were employed as stimuli during equivalence training testing, labelled A1, B1, C1, D1, A2, B2, C2 and D2 (see Table 1) for clarity, although participants were not exposed to the alphanumeric designations. One Red and one Blue solid circle, diameter 3 cm, functioned as visual discriminative stimuli during the simple discrimination task. Eight further nonsense syllables, LIR, FIM, RET, KAV, GIM, JOR, BOC, LUT, labelled A3, B3, C3, D3, A4, B4, C4 and D4 respectively, were employed as stimuli during the complex discrimination task which consisted of further conditional discriminations identical to those employed during stimulus equivalence training.

All interventions were delivered via the computer and the use of a pair of standard lightweight headphones. During the relaxation training a PMR instruction set was delivered in audio via the headphones while a solid green background was displayed on screen (see Appendix).

A paper and pencil questionnaire containing six questions was employed as a manipulation check to assess participant engagement with the intervention procedure. Participants responded to each question using a 10-point Likert scale. The questions were: How relaxing was this experience for you? ; How stimulating was this experience for you? ; How engaging was this experience for you? ; How boring was this experience for you? ; How frustrating was this experience for you? ; How satisfying was this experience for you?

Procedure

The study comprised four phases. Participants were randomly assigned to one of three experimental conditions and completed a consent form. The participants sat facing a computer screen with a mouse positioned at their right-hand side and read the instructions displayed on screen. The experimenter then left the room.

Phase 1: Matching-to-Sample (MTS) Training.

Instructions on how to engage with the MTS tasks were displayed on screen at the beginning of Phase 1 and remained on screen until the participant acknowledged them by pressing the space bar as instructed.

On all trials the sample stimulus appeared in the centre top-half of the screen and the two comparison stimuli to the left and right below the sample at the bottom edge of the screen after a 1 s delay. The left and right positions of comparison stimuli were counterbalanced across trials. Both sample and comparison stimuli remained on screen until the participant clicked on a comparison stimulus using the mouse. While baseline relations were being established correct responses were followed by the presentation of the word “Correct” accompanied by a beep and incorrect responses by “Wrong” with no accompanying sound. The feedback message (“Correct” or “Wrong”) was displayed in the middle of the screen for 1.5 s followed by an inter-trial interval of 1 s. Six baseline relations were trained during MTS training to establish two four-member equivalence relations (see Table 1).

The six trial types were presented quasi-randomly and initially introduced in blocks containing two trial types repeated five times in a quasi-random order. Nine consecutively correct responses in a block of 10 trials were required to complete a block satisfactorily. Participants were recycled through training blocks until they made ≥ 9/10 responses within a block. On reaching this criterion the next pair of randomly selected trial types was presented. Participants were trained to match A1-B1, B1-C1, C1-D1, A2-B2, B2-C2 and C2-D2 (i.e., a linear training protocol). The final training block combined all six trial types in a quasi-random order with each trial type repeated five times. The criterion for completing the final training block was ≥ 29/30 (96.7%) correct responses. Participants who made more than one incorrect response in a block of 30 trials were recycled through further mixed training blocks of 30 trials until this criterion was achieved. Due to ethical considerations a time-limit of 30 minutes was established for this phase. If a participant failed to master the response criterion within this timeframe their participation was terminated and the data treated as a failure to complete training and not included in the subsequent analysis. These participants were fully debriefed and thanked for their participation. When all baseline relations were trained at a minimum of 96.7% correct in the final training block, participants were notified via on-screen instructions informing them how to proceed to contact the experimenter in order to begin the next phase.

Phase 2: Baseline (MTS) Testing.

The MTS training phase was followed by a test block in which baseline relations were tested without the feedback (i.e., A-B, B-C, and C-D). Instructions, sample stimuli and comparisons were presented, and responses recorded, in the same manner as in the training phase. This phase was identical to the mixed trial block at the end of Phase 1 but no feedback was presented. Participants who failed a testing-block (i.e., <100% correct responses) were re-exposed to the training phase until a test-block was passed successfully or until a further thirty minute time limit was reached. Participants who failed to master criterion were deemed to have failed the task, did not proceed to the subsequent phases and their data was not included in the subsequent analyses.

Phase 3: Interventions.

Following successful completion of the baseline test phase, participants progressed to either the relaxation intervention or one of the two non-relaxation interventions (Simple or Complex Discrimination tasks). Participants were randomly assigned to each of the experimental conditions. All three interventions were 11 minutes in duration, immediately after which participants completed the paper and pencil manipulation check questionnaire.

PMR (Relaxation) Condition.

Participants listened to a recorded Progressive Muscle Relaxation (PMR) instruction set based on Jacobsen's (1938) principles (see Appendix). Instructions were displayed on screen informing participants how to proceed. A key press or mouse click removed the instructions from the screen, changed the screen to green and commenced the PMR audio clip.

Non-relaxation Condition 1: Simple Discrimination Task.

Instructions were presented on screen to participants that this task consisted in the presentation of a series of blue and red circles in a random order (4cm diameter approx.), and that they should click only on the red circles. Their objective was to make as many correct responses as possible. Audio response feedback was relayed to participants via the headphones. Stimuli and their on-screen position were quasi-randomly selected across 8 locations. Target stimuli (e.g., a red circle) remained on screen until participants made a correct response. In the absence of a response after 3s the target stimulus was accompanied by the printed instruction "Click On The Red Circle" displayed in the centre of the screen for a duration of 3s. This feedback was presented only once for each target stimulus. A correct response removed the red circle and the instruction stimuli from the screen and initiated the next trial. The second stimulus type (a blue circle) was displayed on screen for 3s, after which the next trial was presented. Responses during this stimulus presentation were punished with verbal feedback. That is, a response to the blue circle led to the presentation of the printed instruction "Don't Click on Blue Circles" in the centre of the screen. Feedback was accompanied by a click sound relayed via the headphones. After 3s the feedback message was removed from the computer screen and the next trial was presented. There was no inter-trial interval. All trials were presented in a quasi-random order such that there were no more than two successive exposures to either trial type.

Non-relaxation Condition 2: Complex Discrimination Task.

The Complex Discrimination task replicated the training delivered in Phase 1 with the exception that it employed novel stimuli unrelated to the rest of the experiment (see Table 1 for trained relations). On-screen instructions mirrored those used in Phase 1.

INSERT TABLE 1 ABOUT HERE

Phase 4: Equivalence Testing.

On-screen instructions informed participants how to respond on trials during this final phase of the experiment. This test phase probed for the emergence of the combined symmetrical and transitive (equivalence) relations. Specifically, it probed for the one-node derived relations C1-A1 and C2-A2, as well as the two-node derived relations D1-A1 and D2-A2. The test block consisted of 40 trials (i.e., each of the 4 trial types presented 10 times each in a quasi-random order) and was administered only once, regardless of performance. Comparisons were presented in the same manner as in Phase 1 training, but no feedback was provided for responses made (see Table 1). The total number of correct responses recorded for each participant was employed as the main dependent measure with which the impact of each intervention on derived relational responding fluency was assessed.

Results

Of the 50 participants the performances of 15 were not included in the final data analyses. Specifically, participants 2 and 16 were dropped from the study as they failed to reach criterion within the established time limit (30 mins) during MTS training. Participants 3, 5, 6, 10, 11, 12, 14, 20, 23, 27, 34, 35 and 42 were excluded because they failed to reach required response fluency (100%) correct during the baseline test, Phase 2. There were 12 participants in both the Simple Discrimination and PMR conditions, with 11 in the Complex Discrimination Condition 2 (i.e., 35 participants in total).

MTS Training

Preliminary inspection of the data showed large variations in the number of training trials required to reach criterion across the groups (see Table 2). However, a Kruskal-Wallis Test found no significant differences in trial requirements χ^2 (2, 35) = .31, p = .857 across conditions, and therefore, any differences in acquisition does not form the basis of differences observed in performance on the subsequent equivalence test. The average number of training trials required to meet criterion (96.7% correct) was 163.71.

Baseline (MTS) Testing

Thirty-five remaining participants reached criterion (100% correct) on their one and only exposure to Phase 2 (see Table 2). A further 13 participants who failed to reach criterion were given the option to repeat Phases 1 and 2 again, but none chose to do so.

Manipulation Check

Inspection of the manipulation check questionnaires suggest that all participants subjective reports reflected that they fully engaged with the interventions insofar as no participant in the relaxation condition rated their experience high (above 5) on stimulation and frustration and no participant in the control groups rated their experience high (i.e., above 5) on relaxation or low (below 5) on stimulation. This suggests that participants in the control groups did not experience the interventions as relaxing and no participant in the PMR condition experienced the intervention as stimulating or frustrating.

Equivalence Testing

Each participant completed one test block comprising 40 trials (20 trial probes for one-node derived relations and 20 trial probes for two-node derived relations). Table 2 shows the number of correct responses recorded for each participant during the equivalence test phase subsequent to exposure to one of the three intervention conditions. Response accuracies were also analysed separately for one-node (derived A-C relations) and two-node (derived A-D relations). The data for total, one-node and two-node derived relational response accuracy were normally distributed for all three conditions Simple, Complex, and PMR.

Of the 35 participants, those in the PMR intervention scored significantly higher mean response accuracies for total (M = 27.83), one (M = 13.50), and two-node (M = 15.17) probe response accuracies than either the Simple or Complex Discrimination interventions, in line with experimental predictions. The mean response accuracy of participants in the Complex Discrimination intervention for total (M = 19.08), one (M = 8.42) and two-node (M = 10.67) probes were the lowest of the three conditions. The mean response accuracy scores for participants in the Simple Discrimination intervention for total (M = 17.64), one (M = 7.00) and two-node (M = 10.36) probes were marginally higher than, but not significantly different from, the response accuracy scores observed in the Complex Discrimination Condition, and significantly lower than those observed for the Relaxation Condition.

Closer inspection of the data also revealed that the highest response accuracy was recorded in the PMR condition. One participant (P15) achieved maximum response accuracy (i.e. 20 out of 20 correct) for both one and two-node derived relational probes, with only one other participant (P26) recording maximum accuracy for two-node probes. Overall, the results suggest that the PMR intervention had an effect on participants' subsequent performance in the equivalence test phase.

INSERT TABLE 2 ABOUT HERE

A one-way between groups analysis of variance (ANOVA) was conducted to explore the impact of intervention type (simple, complex, and relaxation) on derived relational responding. Levene's Test of Equality of Variances violated the assumption of homogeneity of variances $F(2, 32) = 10.637$, $p < .001$, therefore Welch's statistic is reported. There was a statistically significant difference among the groups in derived relational responding, F (2, 32) = 5.26, $p = .015$, with a large effect size ($\eta^2 = .33$; Cohen, 1988). Tukey HSD post-hoc comparisons indicated that the mean score for the Relaxation group ($M = 27.83$, $SD = 9.62$) was significantly greater than both the Simple Discrimination task group ($M = 19.08$, $SD = 4.30$), and the Complex Discrimination task group ($M = 17.64$, $SD = 4.65$). The Simple and Complex Discrimination task groups did not significantly differ from each other.

To assess the impact that the interventions may have had on response time, a one-way between groups ANOVA was conducted. Levene's Test of Equality of Variances violated the assumption of homogeneity of variances $F(2, 32) = 6.66$, $p = .004$, therefore Welch's statistic is reported. No significant differences were found across groups $F(2, 32) = .95$, $p = .41$, which suggests that interventions had no impact on response speed during equivalence testing.

One and two-node probes

The derived relational responding accuracy of participants was separated for one-node and two-node probes. Preliminary statistics showed no violation of the assumptions of normality with Kolmogorov-Smirnov significance value of .2 for groups 1 and 2 for both one and two nodal distances, and a value for group 3 of .16 for one nodal distance and .10 for two-nodal distances. Levene's statistic demonstrated no violation of the assumption of homogeneity of variances, $F(2, 32) = 1.65$, $p = .21$ for one nodal distance and $F(2, 32) = 2.12$, $p = .14$ for two nodes of separation.

A one-way between-groups ANOVA Revealed a statistically significant difference among the groups at the $p < .05$ level for a distance of one-node: $F(2, 22) = 5.861$, $p = .01$, with a large effect size ($\eta^2 = .27$; Cohen, 1988). Tukey HSD post-hoc comparisons indicated that the mean score for the PMR Condition ($M = 13.50$, $SD = 5.54$) was significantly higher than the simple discrimination condition ($M = 8.42$, $SD = 3.80$) and the complex discrimination condition ($M = 7.00$, $SD = 5.00$). The simple and complex discrimination task conditions did not differ significantly from one another. Thus, the relaxation intervention resulted in significantly more accurate responding rates for one-node probe derived relations than either the simple or complex discrimination tasks.

For a distance of two-nodes a one-way between-groups ANOVA also showed a large statistically significant difference between the groups: $F(2, 32) = 4.26$, $p = .02$, $\eta^2 = .21$. Tukey HSD post-hoc comparison tests found that the mean score for the PMR group ($M = 15.17$, $SD = 5.15$) was significantly higher than the mean score for both the simple discrimination ($M = 10.67$, $SD = 4.94$) and complex discrimination groups ($M = 10.36$, $SD = 2.84$). Analyses of the mean derived relational response fluency for a distance of two nodes found that the relaxation intervention again resulted in significantly more accurate response rates than either of the other two non-relaxation interventions..

INSERT FIGURE 1 ABOUT HERE

Discussion

The present study established that a brief relaxation intervention was effective in significantly increasing cognitive performance operationalized as derived relational responding. These findings are consistent with the literature reporting enhancements to cognition following extensive as well as brief meditation training (Krampen, 1997; Rausch, et al., 2006; Zeidan, et al., 2010). Specifically, a single 11-minute PMR exercise was effective in significantly increasing response accuracy compared to the two control groups for both one-node and two-node derived relations.

Crucially the cognitive enhancement following relaxation training was evident for the more simple forms of derived relational responding (one-node probe), in contrast to the cognitive effects observed following sleep in the Ellenbogen, et al. (2007) study. In that study sleep did not enhance performance in deriving one node relations, following a 12 hour post-learning period containing sleep. Furthermore, no significant differences were observed following a 20-minute post-learning period with or without sleep for both one and two node derived relations. Those results contrast with the findings of the present study in which significant improvements in performance were observed for both one and two node derived relations following 11 minutes of PMR. Of course, it is important to acknowledge that there were differences in the training protocols employed across the two studies and the relations were of a different kind ("greater than" relations, as opposed to equivalence relations).

There is a stark contrast between the time frame required to demonstrate significantly improved cognition following relaxation (11 minutes in the current study), and sleep (12 hours) in the Ellenbogen et al. study. Typically, sleep studies employ time periods of between 1 to 12 hours (Mednick, Nakayama, & Stickgold, 2003). While there is a scarcity in the literature investigating the fundamental effects of short naps on cognitive performance, a review of the available literature reported a global beneficial effect on cognition (Ficca, Axelsson, Mollicone, Muto, & Vitiello, 2010). It also highlighted the need for clarification of the crucial sleep factors underlying these benefits (i.e., sleep duration, quality and efficiency). Indeed, sleep quality and efficiency are purported to be related to the preferential enhancement of various aspects of cognition (Diekelmann & Born, 2010). Considering that relaxation, both extensive (Cahn & Polich, 2006) and brief (Hudetz, et al., 2006) not only improves cognition but also sleep onset, quality and efficiency (Pattanashety, et al., 2010), it seems at least tenable that relaxation may underlie the cognitive benefits observed following sleep.

The current study builds on previous research (Zeidan, et al., 2010) that suggests relaxation can have an immediate and significant impact on cognition. This study demonstrated enhanced performance of the core behavioral process underlying human cognition as postulated by RFT (i.e., enhanced derived relational responding) at what is possibly the lowest level of complexity (i.e., one nodal distance). If such significant improvements in this core process can be observed with such a short intervention, the implications for the effects of regular relaxation on everyday low levels of cognition that depend on inference (e.g. numeracy, literacy, creativity) are impressive. That is not to suggest that brief relaxation training is as effective as extensive long-term training schedules, the long lasting effects of which are well documented in the literature (Davidson et al., 2003; Lazar et al., 2005). However, the immediate and short term benefits may make relaxation techniques more attractive if they are shown to be effective in the absence of extensive training, thus enhancing the versatility of their employment in a variety of settings including medical, academic and the workplace environment.

Traditionally a criterion of 90% accuracy is used to define the emergence of stimulus equivalence, whereas in the current study a criterion of 100% was applied. When a criterion of 90% accuracy (i.e., 36 correct out of 40) is employed to define a “pass” during equivalence testing in the current study, 4/12 (33.33%) participants in the PMR condition demonstrated stimulus equivalence. However, none of the participants in the other two conditions reached this criterion. The effect of the relaxation intervention on pass rates at 90% accuracy is more pronounced when different nodal distances are considered separately. During the one-node equivalence testing trials, 5/12 participants (41.67%) in the PMR condition passed equivalence testing, whereas only 1/11 (9%) and 0/11 (0%) participants passed in the complex and simple discrimination conditions, respectively. The effect was even more distinct at a distance of two nodes, with 6/12 participants (50%) in the PMR condition reaching the 90% pass criterion. Only 1/12 (8%) participants reached tis criterion in the simple discrimination condition and none in the complex discrimination condition.

These pass rates may appear low in comparison to other stimulus equivalence studies. However, it must be borne in mind that there was only one exposure to a 40 trial testing block in this study, whereas repeatedly exposing participants to the testing block, even following further baseline relations training, is typically reported in the literature. For this reason, performances should not be compared directly compared to those reported in other studies in terms of “yield”. In addition, increases in the number of equivalence class members have been shown to decrease responding in accordance with stimulus equivalence (Saunders, Chaney, & Marquis, 2005). This study involved a four-member stimulus class, and in this respect a yield of 50% following a single test block might even be considered high, especially given that the linear training protocol employed has been identified as likely the least fruitful of the training protocols (e.g., Arntzen, 2004).

A possible mechanism to help account for superior performance of the PMR group may involve a neural process of retroactive interference occurring in the Discrimination task conditions (e.g., Wixted, 2004). Wixted (2005) argued that much ‘forgetting’ is due to non-specific retroactive interference that acts on memory traces that have not yet had time to consolidate in the hippocampus. Wixted (2004, 2005) proposed that new memories are fragile and need time to consolidate in the hippocampus. During this time the new memories (e.g., trained MTS baseline relations) are particularly vulnerable to interference from any new learning, and importantly, the new stimulus material learned does not need to be similar in content and, therefore, the recently learned relations are not necessarily susceptible to proactive interference. Thus, in the present study the PMR intervention involved no new learning, which may have allowed the recently learned MTS baseline relations the time to consolidate in the hippocampus without being interfered with. In contrast, while the Simple and Complex Discrimination condition tasks were not cognitively taxing on the participants, and were not similar in content to the earlier MTS training tasks, they still required a degree of discriminating and learning, which placed demands on the limited capacity of the hippocampus. Thus, this new learning task hindered the consolidation of the previously learned MTS baseline relations. This same process may still apply during sleep periods (e.g., Born, et al., 2006; Stickgold, 2005; Marshall & Born, 2007), and thus it may be that both relaxation and sleep facilitate enhanced cognition via reduction in retroactive interference on newly learned material, rather than via their common stress reduction properties as suggested in research cited earlier.

Of course, the forgoing interpretation of the current effects is framed in cognitive and neurobiological terms and still leaves unanswered the question of what behavioral process may be involved in the enhancement of learning by relaxation interventions. It may well be that the effects of baseline relation training requires time to yield derived relations, even if the process at work during that time are of no interest to a behavioral psychologist. The requirement of time for training to take effect does not necessitate the entertainment of mediating processes for a psychologist interested only in the prediction and influence of behavior. For those working from such a perspective we can offer a more parsimonious explanation of the current effects in terms of behavioral competition. Put simply, requiring an organism to engage in an unrelated cognitive task and preventing the non-stimulating passage of time required for training to have its effects (e.g., a complex discrimination task), may simply constitute behavioral competition, that reduces the efficiency of the training method. This may even apply to routine stimulus equivalence training procedures in which a break is rarely given to participants between training and testing blocks. The current research suggests that at the very least, a short break involving undirected attention (i.e., passive relaxation) between training and testing phases may enhance equivalence yields, but this remains to be tested specifically in future research.

The results of the present study suggest that brief PMR training enhances cognitive performance on stimulus equivalence tasks. Importantly, the stimulus equivalence task employed here is of great interest to behaivor analysts and is of relevance to many forms of complex behavior studied by those of a behavior-analytic persuasion. In effect, this helps to underscore the relevance of the benefits of relaxation, insofar as it appears to enhance performance on a task that many researchers use as paradigm for understanding a wide variety of important cognitive activities.

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Table 1.

The stimulus relations (sample stimuli, correct, and incorrect comparison stimuli) trained in the MTS Training, trained relations in the Complex Discrimination Task, and relations probed for in the Equivalence Test phase. The actual nonsense syllables employed are in parentheses.

MTS Training

Stimulus	Correct Choice	Incorrect Choice
A1 (Cug)	B1 (Pav)	B2 (Ker)
B1 (Pav)	C1 (Vek)	C2 (Lef)
CI (Vek)	D1 (Jom)	D2 (Mau)
A2 (Zid)	B2 (Ker)	B1 (Pav)
B2 (Ker)	C2 (Lef)	C1 (Vek)
C2 (Lef)	D2 (Mau)	D1 (Jom)

Complex Discrimination task.

Stimulus	Correct Choice	Incorrect Choice
A3 (Lir)	B3 (Fim)	B4 (Jor)
B3 (Fim)	C3 (Ret)	C4 (Boc)
C3 (Ret)	D3 (Kav)	D4 (Lut)
A4 (Gim)	B4 (Jor)	B3 (Fim)
B4 (Jor)	C4 (Boc)	C3 (Ret)
C4 (Boc)	D4 (Lut)	D3 (Kav)

Equivalence Test phase

Stimulus	Correct Choice	Incorrect Choice
C1 (Vek)	A1 (Cug)	A2 (Ker)
D1 (Jom)	A1 (Cug)	A2 (Lef)
C2 (Lef)	A2 (Zid)	A1 (Cug)
D2 (Mau)	A2 (Zid)	A1 (Cug)

Table 2.

Participant trial requirements for baseline relation training (Phase 1), total number of correct responses on the baseline relations test (Phase 2), total number correct during the equivalence test (Phase 3), along with a breakdown of the total number of correct responses to one-node and two-node derived relations probes during Phase 3. Participant condition is indicated in the second column.

		Phases 1 & 2			**Phase 3**	
Participant	Condition	Training Trials Required	Baseline Test Total Correct	Total No. Correct	One-Node No. Correct	Two-Node No. Correct
1	Simple	180	30	20	12	8
4	Simple	580	30	15	7	8
7	Simple	130	30	20	9	11
13	Simple	220	30	18	17	1
19	Simple	120	30	19	10	9
22	Simple	140	30	29	9	20
30	Simple	330	30	14	7	7
36	Simple	80	30	17	3	14
37	Simple	100	30	18	5	13
45	Simple	130	30	14	6	8
46	Simple	110	30	21	5	16
47	Simple	150	30	24	11	13
8	Complex	180	30	12	7	5
17	Complex	100	30	29	19	7
25	Complex	140	30	21	8	13
28	Complex	100	30	16	2	14
33	Complex	210	30	20	10	10
39	Complex	330	30	19	11	8
41	Complex	120	30	14	3	11
43	Complex	120	30	15	6	9
44	Complex	110	30	17	4	13
48	Complex	150	30	17	5	12
49	Complex	130	30	14	2	12
9	PMR	180	30	15	11	4
15	PMR	80	30	40	20	20
18	PMR	180	30	15	5	10
21	PMR	240	30	18	8	10
24	PMR	210	30	19	7	12
26	PMR	120	30	39	19	20
29	PMR	110	30	36	19	17
31	PMR	200	30	22	8	14
32	PMR	90	30	27	19	18
38	PMR	120	30	37	18	19
40	PMR	120	30	34	15	19
50	PMR	120	30	32	13	19

Figure 1.

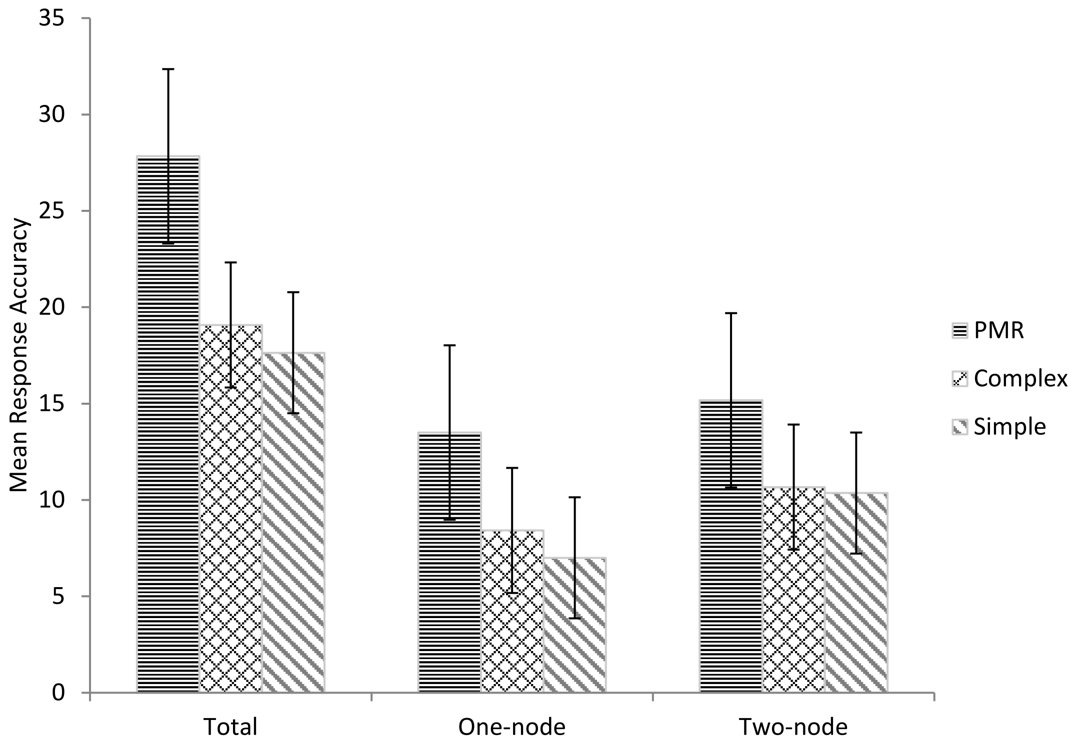
35
30
25
20
15
10
5
0
Mean Response Accuracy
Total
One-node
Two-node
PMR
Complex
Simple

Figure Caption

Figure 1: Mean total, mean one-node and mean two-node correct responses during stimulus equivalence testing (Phase 3) for all three conditions.

Appendix 1: PMR Instruction set script.

Hello, make yourself comfortable. Sit back and close your eyes. I am going to read out some instructions I would like you to follow. Become aware of your breathing. Slowly, breathe in and out through your nose. On each exhale, say the word “one” to yourself. It is natural for thoughts to come into the mind. This does not mean that you are not following the procedure. When this happens, simply, just deal with the thought, do not dwell on it, but return your focus back to your breathing. Breathing in through your nose and exhaling on one. So now, deeply relax all your muscles, starting with your toes, feel them relaxing, all tension easing away, next your ankles. Completely relaxing, no tension at all. Relax the muscles in your calves. No strain. And your knees, feel them relaxing. And all the while, you are breathing in through your nose and exhaling on one. The muscles in your thighs are completely relaxed. The tension is easing away. And your lower back is totally at ease. Completely comfortable. Feel your stomach muscles relaxing. Everything is easing away. And your chest muscles, the tension is leaving them. You are totally at ease. Your hands are completely relaxed, just resting there. There is no tension in your arms. Completely relaxed. Your shoulders, there is no tension in them at all. Totally at ease. Your shoulder blades, feel them relaxing. Letting everything go. And all the while, you are breathing in and exhaling on one. All strains are leaving your neck. Completely relaxed. And your mouth is loosening up, all tension is easing away. Your cheeks are relaxing. Easing out. The lines of your forehead are disappearing. They are being rubbed away, and completely at ease. The top of your head is totally relaxing – no tension at all. Your whole body is completely relaxed. So now you are totally at ease, and continue to relax. Open your eyes whenever you feel ready. Someone will be with you in a few moments.