British Journal of Health Psychology (2006), 11, 717–733
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Longitudinal gains in self-regulation from regular physical exercise

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Objectives. The purpose of the present study was to test whether the repeated practice of self-regulation could improve regulatory strength over time.

Method. Regulatory performance was assessed at baseline, then at monthly intervals for a period of 4 months using a visual tracking task. Perceived stress, emotional distress, self-efficacy and general regulatory behaviour were assessed by questionnaire. Following a 2-month control phase, participants entered a 2-month self-regulation programme designed to increase regulatory strength: a programme of regular physical exercise.

Results. Relative to the control phase, participants who exercised showed significant improvement in self-regulatory capacity as measured by an enhanced performance on the visual tracking task following a thought-suppression task. During the regulatory exercise phase, participants also reported significant decreases in perceived stress, emotional distress, smoking, alcohol and caffeine consumption, and an increase in healthy eating, emotional control, maintenance of household chores, attendance to commitments, monitoring of spending and an improvement in study habits. The control phase showed no systematic changes in performance on the visual tracking task across sessions. Reports of perceived stress, emotional distress and regulatory behaviours were also stable across sessions.

Conclusions. The uptake and maintenance of an exercise programme over a 2-month period produced significant improvements in a wide range of regulatory behaviours. Nearly every major personal and social problem has some degree of regulatory failure. The idea that the capacity for self-regulation can be improved is therefore of vast practical importance.

Self-regulation involves the capacity to override and alter undesirable responses (Baumeister, Heatherton, & Tice, 1994). Exerting self-regulation is often difficult. Whether it is eating or drinking too much, spending instead of saving, or daydreaming instead of finishing a manuscript, failures to regulate one's own behaviour are common. These failures sometimes lead to devastating consequences. For instance, regulatory failures have been linked to substance abuse, criminal behaviour, sexually transmitted

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DOI:10.1348/135910706X96481

diseases and consumer debt (Baumeister *et al.*, 1994). It is therefore essential to understand the processes of self-regulation and the parameters that determine its success.

Researchers have theorized that self-regulation is governed by a limited resource that allows people to control impulses and desires (Muraven, Tice, & Baumeister, 1998). Although the exact nature of this resource remains unclear, this model conceptualizes self-regulation as operating like a 'muscle'. Any regulatory act depletes this muscle, leaving less available strength for subsequent regulatory tasks (Muraven & Baumeister, 2000). In a series of experiments, participants who were instructed to engage in a form of self-regulation (e.g. thought suppression or emotional control) were less able to self-regulate in subsequent regulatory tasks in a variety of behavioural domains (Muraven *et al.*, 1998).

Although our regulatory resources appear to be easily depleted, the effect of depletion manipulations is not inevitably a loss of self-regulatory behaviour. Individuals who are sufficiently motivated may be able to override the effects of depletion, even when the motivation is small, such as the chance to help scientific research (Muraven & Slessareva, 2003). This suggests that depletion and motivation jointly determine regulatory success.

Beyond motivation, there is further reason for optimism. Individuals who practise self-regulation may be able to improve their regulatory abilities. Whilst physical exercise fatigues muscles and leads to poorer performance in the short term, exertion over the long term, however, leads to greater strength. Self-regulatory exercises over 2 weeks, such as posture regulation, keeping a food diary (Muraven, Baumeister, & Tice, 1999), modifying verbal habits, or using the nonpreferred hand (Oaten, Cheng, & Baumeister, unpublished data) led to improvements on laboratory tasks of self-regulation. Improvement was in the form of increased stamina (resistance to the debilitating effects of resource depletion), rather than increased capacity.

These initial studies provide preliminary evidence that our regulatory resource may be improved, but the findings are limited. The regulatory exercises were artificial and short (2 weeks) in total duration. In addition, only a single laboratory task was measured in each experiment. The present research had subjects literally exercising, that is, begin and maintain a programme of cardiovascular exercise. This is a form of self-regulatory exercise that many aspire to do. The health benefits of regular physical activity are widely recognized, while inactivity is associated with increased risk of coronary heart disease, various cancers, obesity and other health problems (Eaton & Eaton, 2003).

Recent efforts at health promotion have been frustratingly ineffective. The prevalence of inactivity-related conditions, such as obesity and type-2 diabetes, has skyrocketed in recent decades (National Centre for Health Statistic, 1999). In fact, in the United States it has been reported that obesity will soon overtake smoking as the primary cause of preventable deaths (Butler, 2004). Furthermore, recent research suggests that most adults are inactive or irregularly active and that approximately 50% of adults joining exercise programmes will drop out within 3–6 months (Dishman, 1988; Sullum, Clark, & King, 2000). In general, the study of barriers to exercise has focused on common negative perceptions, such as lack of time, the cost of exercising, lack of energy and risk of injury. Recently, however, self-regulatory failure has been cited for the generally disappointing outcomes of exercise initiation and adherence programmes (Karoly *et al.*, 2005). The uptake and maintenance of an exercise programme thus seems to require significant regulatory effort.

Present research

Subjects maintained an exercise programme and were measured both in a laboratory task of visual tracking under distraction, and on many self-reported everyday regulatory behaviours. In experimental design, three cohorts participated for free gym membership. Each cohort was measured at the commencement of the exercise programme, and 1 and 2 months into the programme. For controls, two cohorts (cohorts 2 and 3) were also measured twice more before the commencement of the exercise programme. Rather than merely not exercising, the ideal control phase would involve participants engaging in a behaviour that is matched to the exercise phase in every way except the critical feature of requiring self-regulation. It was of concern, however, that the monitoring of any behaviour over the control phase would involve the demand characteristic of self-regulation, thereby failing to provide appropriate controls. The waiting list control phase (no exercise) was therefore selected.

If the repeated practice of self-regulation does augment regulatory resources, we predict: (1) Improvement in regulatory behaviour (as measured by an attenuated rate of depletion) across the exercise phase. Predictions are same for each cohort across the exercise phase; and (2) No change in regulatory behaviour (as measured by a constant rate of depletion) across the waiting list control phase.

Method

Participants

Twenty-four sedentary undergraduates across Macquarie University (6 males and 18 females) volunteered in return for gym membership at the Macquarie University Sports Association. The age of participants ranged from 18 to 50 years, with a mean age of 24 years (*SD* 6 years).

Participants were recruited via campus flyers. Our initial recruitment retained 15 participants (cohorts 1 and 2). Due to low participant numbers, we readvertised the study with another campus recruitment later in the semester (cohort 3). Participants who failed to attend the initial session were not rescheduled for study participation; only those participants who attended the initial session were enrolled into the research programme.

Participants were randomly assigned to one of three cohorts (cohorts 1, 2 and 3). Cohort 1 ($N = 9$; two males and seven females) entered the exercise programme directly and was individually tested in three 30-minute sessions, separated by 4-week interim periods. Cohorts 2 ($N = 6$; two males and four females) and 3 ($N = 9$; two males and seven females) entered the wait-list control phase before proceeding to the exercise programme, and were individually tested in five 30-minute sessions, separated by 4-week interim periods.

Design

Table 1 shows the schedule of testing for the three cohorts. One cohort (cohort 1) entered the exercise programme directly. Two cohorts (cohorts 2 and 3) had 2 months on the waiting list, during which they did not exercise, before entering the exercise programme. This served as within-subjects and between-subjects control for the effects of the exercise programme. All testing sessions were uniform. Experimental sessions were separated by 4-week periods. Exercise programmes were tailored to suit the individual by gym staff, and included aerobic classes, free-weights, and resistance training.

Table 1. Exercise programme (in months)

Programme	October	November	December	January	February	March	April
Cohort 1	E	E	E				
Cohort 2	C	C	C/E	E	E		
Cohort 3			C	C	C/E	E	E

C, waiting list control; E, 3–4 times per week of cardiovascular exercise; C/E, end of control phase/beginning of exercise phase.

Self-report measures

The general health questionnaire

Emotional distress was assessed in all sessions using the 28-item version of The General Health Questionnaire (GHQ; Goldberg, 1972). The questionnaire referred to respondents' experiences over the past week and was coded using a method that assigns weights of 0, 1, 2 and 3 to each answer option. The GHQ has a high degree of internal consistency with a reported Cronbach's alpha of .87, and good test–retest with a reported Cronbach's alpha of .88.

Perceived stress scale

Perceived stress was measured in all sessions using the 10-item version of the Perceived Stress Scale (PSS; Cohen, Kamarck, & Mermelstein, 1983). The PSS was used to assess the degree to which situations in life were appraised as stressful over the past week. Each item was assessed on a five-point scale, with higher scores indicating greater stress. The PSS is a reliable measure of perceived stress with an overall Cronbach alpha of .87 and a retest reliability of .85.

General self-efficacy scale

Self-efficacy was measured in all sessions using the 10-item version of the General Self-Efficacy Scale (GSES; Jerusalem & Schwarzer, 1992). Each item was assessed on a five-point scale, with higher scores indicating higher perceived self-efficacy. The scale has typically yielded internal consistencies between $\alpha = .76$ and .91, and retest reliability is satisfactory at .75.

General regulatory behaviour questionnaire

A questionnaire was designed to assess cigarette smoking, alcohol and caffeine consumption and everyday regulatory behaviours. The questionnaire was administered in all sessions. The test–retest reliability of the questionnaire is reported in the Results (see Table 3).

Cigarette smoking, caffeine and alcohol consumption were assessed by the use of open-ended questions presented in questionnaire format. Current cigarette smoking was estimated as the number of cigarettes smoked over the past 24 hours. Current alcohol and caffeine consumption were assessed using a 7-day recall procedure, with quantity being the measure of interest.

Various everyday behaviours that involve self-regulation (e.g. 'In the last week, how often did you go out with friends instead of studying?') were also measured. Response sets were recorded on a five-point scale. Twelve measures were derived for analysis:

dietary habits (healthy food choice, junk food consumption), self-care habits (flossing teeth, leaving dishes in the sink, sleeping in), spending habits (impulse spending, overspending), emotional control (loss of temper), keeping appointments (sticking to schedule, procrastination), and study habits (spending time with friends instead of studying, watching television instead of studying).

Visual tracking under distraction

A laboratory task of self-regulation was administered twice in each testing session. Participants performed a computerized visual tracking task (VTT) while a distracter video simultaneously played in front of the participant. The VTT required participants to track the movement of multiple independent targets displayed on a computer monitor (Pylyshyn & Storm, 1988; Scholl, Pylyshyn, & Feldman, 2001). The VTT stimuli are visually indistinguishable. Therefore, participants must ignore the distracter video to track the VTT targets accurately (see Figure 1). The distracter video included excerpts from a performance by Eddie Murphy (Murphy, Tieken, & Wachs, 1983). The use of the VTT to assess self-regulatory capacity has been validated in previous research (Oaten & Cheng, in press).

Stimuli were displayed on an i-Mac™ computer equipped with a 15″ monitor set to a resolution of 800 × 600 pixels and a refresh rate of 95 Hz. Participants were seated 54 cm away from the monitor. The VTT was controlled and measured using Psyscript (Bates & D'Oliviero, 2000). Each VTT consisted of 16 trials. At the beginning of each trial, six black squares (20 × 20 mm) were presented in a horizontal line (Figure 1). After 2 seconds, three target items were highlighted with small flashing probes (disappearing and reappearing for five flashes). Then all six items moved in random trajectories for 5 seconds. After all of the items stopped moving, the subject had to indicate the three target items using the mouse. The final mouse-click caused the display to disappear, and the subject initiated the next trial with a key-press. Forty-eight sets of trajectories (along with target selections) were generated and stored off-line. Subjects completed a practice trial for which the data were not collected, and then completed the experimental trials in a randomized order (different for each subject).

Thought suppression task

Following the initial assessment of self-regulatory performance, a thought suppression exercise was administered to manipulate regulatory exertion. The procedure, developed by Wegner, Schneider, Carter, and White (1987), requires the participant not to think about a white bear. This task has been used previously to deplete self-regulatory strength (Muraven *et al.*, 1998, 1999). Participants were instructed to list any

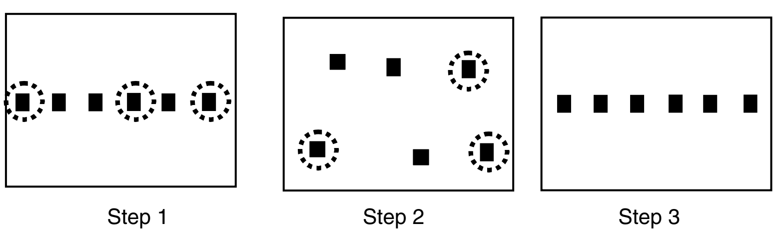

Figure 1. A representation of a VTT trial sequence.

thoughts that came to mind with the admonition that they should avoid thinking about a white bear. They were told that whenever they thought of a white bear, they should write that thought down (Muraven *et al.*, 1998). The experimenter emphasized that it was very important to immediately change their thoughts and to try very hard not to think of a white bear again. Following the thought suppression exercise, a post-measure of self-regulatory performance was recorded by administering a second VTT.

Manipulation checks
The exercise frequency log and exercise diaries were employed as manipulation checks to ensure that participants were adhering to the exercise programme.

Exercise frequency log
Frequency of exercise participation was assessed by having participants complete an exercise register at the beginning of every exercise session during the programme. For the purpose of analyses, frequency was defined as the total number of times that participants had exercised.

Exercise diaries
Exercise diaries were employed to assess the ease of uptake and maintenance of the exercise programme. As part of their diary logs, participants were asked the following questions: 'What level of difficulty, if any, have you experienced complying with the programme?'; 'Do you feel you are progressing with the programme?'; 'Do you wish to comment on the programme generally?'. Participants were instructed to record their progress in the diaries provided and to return them to the experimenter.

Waiting list control
Participants (cohorts 2 and 3) spent 2 months on the waiting list. During this period they behaved like the experimental group (i.e. attending experimental sessions), except they did not exercise before entering the exercise programme.

Procedure
In each session, participants were administered (in order) a visual tracking task, the thought suppression task and then a second visual tracking task. Measures of emotional distress, perceived stress, self-efficacy and general regulatory behaviours were then obtained. Data collection was conducted between Tuesday and Friday of each week, so that all smoking information related to a weekday.

Results
We sustained a participant retention rate of 100%. All participants who attended the initial session also attended the intervening and final sessions.

Manipulation checks
Exercise frequency log
The exercise frequency log (as measured by gymnasium attendance registrations) indicated that participants did adhere to the exercise programme. Figure 2 summarizes

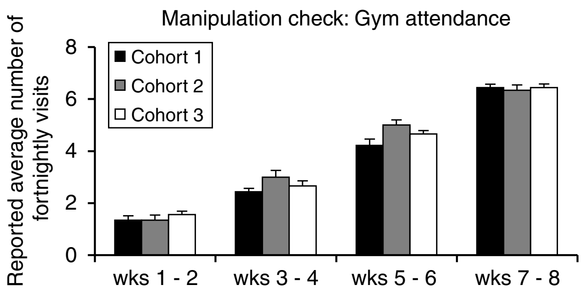

Figure 2. Reported average number of fortnightly visits to the gymnasium ($M \pm SE$), across the exercise phase.

the mean exercise frequencies. The reported exercise frequencies were entered into a weeks (1–2, 3–4, 5–6, 7–8) × cohort (1, 2, 3) repeated measures ANOVA. The ANOVA found a significant main effect for weeks, $F(3, 63) = 149.92$, $p < .001$. These results suggest that not only did participants attend the gymnasium, but also attendance increased over time. No other effects were significant.

Exercise diaries

All exercise diaries were returned to the experimenter as instructed. An inspection of the diaries indicated that all participants recorded progress on the exercise programme as instructed. Accordingly, the diary content suggested a roughly equal expenditure of effort from all participants.

Visual tracking task

Within-subjects effects

Figure 3 summarizes performance on the visual tracking task across the exercise phase. All three cohorts participated in the exercise phase and were included in the analyses. A session (baseline, 1 month, 2 months) × time (pre- vs. post-thought suppression) repeated measures ANOVA found significant main effects for time, $F(1, 23) = 966.34$, $p < .001$, indicating a general tendency toward depletion following a previous self-regulatory act, a significant main effect for session, $F(2, 46) = 329.84$, $p < .001$, suggesting that visual tracking performance improved across sessions, and importantly, a significant session × time interaction, $F(2, 46) = 315.34$, $p < .001$. The pattern of

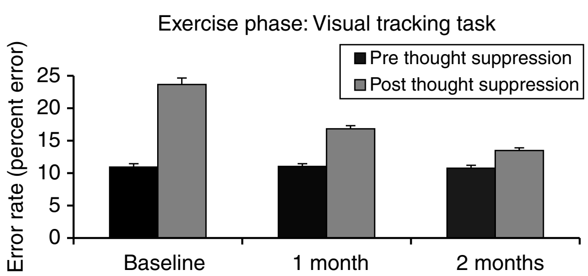

Figure 3. Error rate on the visual tracking task ($M \pm SE$), measured before and after the thought suppression task, across the exercise phase.

results indicates that the exercise programme improved regulatory stamina, increasing resistance to the debilitating effects of a manipulation of regulatory depletion (a thought suppression task) across the exercise phase.

Between-subjects effects

The exercise phase and the control phase were also compared across cohorts. With three cohorts being tested over different but overlapping time-lines (see Table 1), two mixed analyses with session and time serving as within-subjects variables and cohort as the between-subjects variable were conducted. The first ANOVA compared cohorts 1 and 2, with session (baseline, 1 month, 2 months) $\times$ time (pre- vs. post-thought suppression) $\times$ cohort (cohort 1 [exercise phase] vs. cohort 2 [control phase]) as factors. The ANOVA found significant main effects for time, $F(1, 13) = 268.15$, $p < .001$, and session, $F(2, 26) = 98$, $p = .01$. There was also a significant session $\times$ time interaction, $F(2, 26) = 15.72$, $p < .001$, a significant time $\times$ cohort interaction, $F(2, 26) = 23.75$, $p < .001$, indicating that the rates of depletion differed across the groups, a significant session $\times$ cohort interaction, $F(2, 26) = 10.76$, $p < .001$, indicating that overall visual tracking performance differed across groups, and a significant session $\times$ time $\times$ cohort interaction, $F(2, 26) = 23.80$, $p < .001$, indicating a pattern of performance consistent with improved stamina in the exercise group but not the control group.

A second session (baseline, 1 month, 2 months) $\times$ time (before thought suppression vs. after thought suppression) $\times$ cohort (cohort 2 [exercise phase] vs. cohort 3 [control phase]) repeated measures ANOVA was conducted (see Table 1). Session and time served as the within-subjects variables, and cohort (this time cohort 2 and 3) was the between-subjects variable. Consistent with the above-mentioned findings, there were significant main effects for time, $F(1, 13) = 321.22$, $p < .001$, and session, $F(2, 26) = 3.84$, $p = .03$. There was also a significant session $\times$ time interaction, $F(2, 26) = 8.53$, $p < .001$, a significant time $\times$ cohort interaction, $F(2, 26) = 25.26$, $p < .001$, a significant session $\times$ cohort interaction, $F(2, 26) = 9.31$, $p < .001$, and a significant session $\times$ time $\times$ cohort interaction, $F(2, 26) = 11.27$, $p < .001$, again indicating a pattern of performance consistent with improved stamina in the exercise group, not matched in the control group.

The reported significance of inferential statistics for the repeated measures ANOVAs remained unchanged when Greenhouse–Geisser corrected.

It was of interest to test whether VTT performance (pre- and post-thought suppression) differed at each testing session. Performance on the VTT (pre- and post-thought suppression) at each testing session was entered into protected paired t tests ($\alpha = .05/3$). There was a significant difference between pre- and post-suppression VTT performance at each testing session of the exercise phase, baseline, $t(23, [M.\text{diff} = -12.75]) -20.647$, $p < .001$; 1 month, $t(23, [M.\text{diff} = -5.79]) -25.735$, $p < .001$; 2 months, $t(23, [M.\text{diff} = -2.75]) -12.551$, $p < .001$. These findings suggest that the exercise programme helped to reduce, but not eliminate, the effects of depletion.

General regulatory behaviour

Figures 4–6 show the reported changes in regulatory behaviours across the exercise phase. All three cohorts participated in the exercise phase and were included in the analyses. The data in Figures 4–6 were entered into a repeated measures analysis

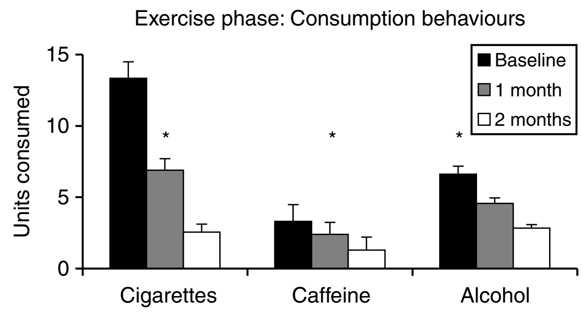

Figure 4. Number of cigarettes (over 24 hours), cups of caffeine and standard units of alcohol (over 7 days) across the exercise phase ($M \pm SE$). Analyses of behaviour were restricted to those individuals who engaged in these activities, rather than the entire sample (*$p < .05$). There was no interaction with the cohort.

Figure 5. General regulatory behaviour across the exercise phase ($M \pm SE$). Frequency of behaviours: 0 = never; 1 = once per week; 2 = 2–3 times per week; 3 = daily; 4 = more than once per day (*$p < .05$). There was no interaction with the cohort.

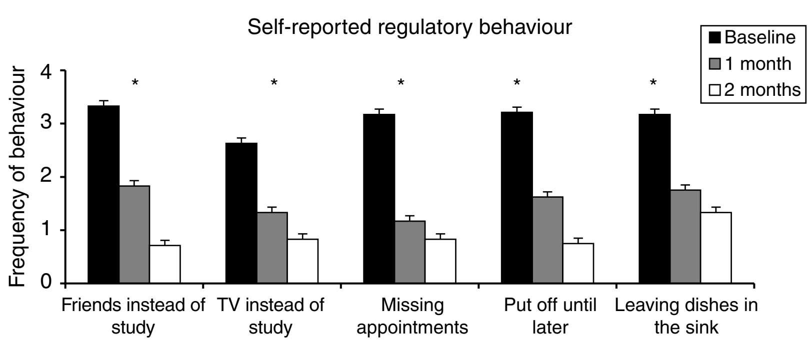

Figure 6. General regulatory behaviours across the exercise phase ($M \pm SE$). Frequency of behaviours: 0 = never; 1 = once per week; 2 = 2–3 times per week; 3 = daily; 4 = more than once per day (*$p < .05$). There was no interaction with the cohort.

of variance, with session (baseline, 1 month, 2 months) as the within-subjects factor. Analyses of each behaviour were restricted to those individuals who engaged in these activities, rather than the entire sample. Table 2 summarizes the main effects of session.

Table 2. Inferential statistics on regulatory behaviours (cohort 1 [exercise] vs. cohort 2 [control]) and (cohort 2 [exercise] vs. cohort 3 [control])

	Cohort 1 vs. Cohort 2			Cohort 2 vs. Cohort 3		
Consumption behaviour	df	*F*	*p*	df	*F*	*P*
Cigarettes	2, 6	18.20	<.001	2, 8	1282.67	<.001
× Cohort		18.20	<.001		1282.67	<.001
Alcohol	2, 22	3.28	.01	2, 16	4.87	.02
× Cohort		3.26	.01		4.86	.02
Caffeine	2, 20	5.52	.01	2, 22	5.60	.01
× Cohort		2.36	.01		6.16	.01
General regulatory behaviour						
Junk food	2, 26	2.68	.01	2, 26	6.28	<.001
× Cohort		7.48	.01		9.36	<.001
Healthy habits		6.09	.01		3.81	.03
× Cohort		3.99	.03		3.81	.03
Impulse spending		9.39	<.001		12.96	<.001
× Cohort		8.14	<.001		10.30	<.001
Over-spending		2.87	<.001		.55	.01
× Cohort		1.80	.01		.17	.01
Losing temper		3.71	.03		2.82	<.001
× Cohort		1.76	.02		4.02	.03
Friends instead of study		7.24	<.001		8.55	<.001
× Cohort		15.02	<.001		6.18	<.001
TV instead of study		2.45	.01		2.46	.01
× Cohort		2.37	.01		1.40	.03
Missing appointments		4.64	.02		7.78	<.001
× Cohort		7.08	<.001		4.31	.02
Put off until later		4.36	.02		5.85	.01
× Cohort		4.47	.02		6.88	<.001
Leaving dishes in sink		3.24	.03		9.55	<.001
× Cohort		7.94	<.001		5.15	.01
Flossing teeth		.08	.92		.37	.69
× Cohort		3.60	.08		.37	.69
Sleeping in		.66	.53		2.46	.11
× Cohort		.24	.78		.77	.47

As predicted, people seemed better able to control their behaviour following the exercise programme. In fact, all of the behaviours, with the exception of flossing teeth and sleeping in, show significant changes in the predicted direction. Chemical consumption decreased (Figure 4). Over 2 months, smoking decreased by a mean of 10 cigarettes per day, caffeine consumption decreased on average by five cups per week, and alcohol decreased on average by five drinks per week. Junk food intake decreased across sessions, whereas healthy eating habits increased (Figure 5). General regulatory habits improved across sessions (Figures 5 and 6). During the exercise phase, participants reported an increase in emotional control and a decrease in impulse spending, overspending, watching television instead of studying, spending time with friends instead of studying, failures to attend commitments and procrastination. Domestic habits also improved with participants leaving the dishes in the sink less often (Figure 6). There was no significant difference across sessions for flossing teeth or sleeping in, and this may be due to the poor retest reliabilities of these measures (see Table 3).

Table 3. Summary of regulatory behaviours in the control phase: mean (standard error); test-retest reliability (R)

	Mean (SE)			
Behaviour of interest	Control 1	Control 2	Control 3	Test–retest *r*
Emotional responses				
Perceived stress scale ($N = 15$)	19.7 (1.6)	20.2 (1.8)	19.3 (1.3)	.82**
General health questionnaire	26.1 (1.5)	26.5 (2.9)	26.4 (3.4)	.79**
Self-efficacy	29.7 (5.5)	28.2 (7.9)	29.7 (5.5)	.85**
Consumption behaviour				
Cigarettes ($N = 6$)	14.2 (1.5)	14.2 (1.5)	14.2 (1.5)	.1**
Alcohol ($N = 10$)	6.0 (1.2)	6.2 (1.2)	6.0 (1.2)	.98**
Caffeine ($N = 13$)	3.2 (0.6)	3.2 (0.6)	3.0 (0.5)	.99**
General regulatory behaviour				
Junk food ($N = 15$)	3.1 (1.1)	3 (0.7)	3.3 (0.7)	.75**
Healthy eating	2.1 (1.0)	2.1 (0.5)	2.1 (0.6)	.93**
Impulse spending	3.3 (0.2)	3.1 (0.2)	3.2 (0.2)	.86**
Over-spending	2.5 (0.4)	2.5 (0.3)	2.4 (0.3)	.76**
Losing temper	2.3 (0.3)	2.1 (0.3)	2.2 (0.3)	.95**
Friends instead of study	3.2 (0.2)	3.4 (0.2)	3.3 (0.2)	.76**
Television instead of study	2.5 (0.3)	2.5 (0.2)	2.7 (0.3)	.94**
Missing appointments	3.1 (0.3)	3.1 (0.3)	3.3 (0.2)	.94**
Put off until later	3.3 (0.3)	3.5 (0.2)	3.3 (0.3)	.91**
Leaving dishes in sink	3.3 (0.2)	3.2 (0.2)	3.2 (0.2)	.75**
Flossing teeth	1.7 (0.4)	1.7 (0.4)	1.7 (0.4)	.38
Sleeping in	2.1 (0.3)	2.5 (0.3)	2.8 (0.2)	.05

**Correlation is significant at the 0.01 level (two-tailed).
Note. The last session in the control phase is also the first session in the exercise phase.

As with the VTT, mixed analyses of variance comparing the exercise phase with the control phase within a single statistical test was conducted. Due to the different testing time-lines across groups (see Table 1), each dependent variable in Figures 4–6 was entered into two separate analyses: a session (baseline, 1 month, 2 months) × cohort (cohort 1 [exercise phase] vs. cohort 2 [control phase]) repeated measures ANOVA, and a session (baseline, 1 month, 2 months) × cohort (cohort 2 [exercise phase] vs. cohort 3 [control phase]) repeated measures ANOVA. Table 2 summarizes the inferential statistics on general regulatory behaviour for cohort 1 (exercise phase) vs. cohort 2 (control phase), and for cohort 2 (exercise phase) vs. cohort 3 (control phase), respectively. Consistent with the within-subjects analyses, significant cohort by session interactions indicate that regular physical activity led to improved self-regulation in all variables except sleeping in and flossing, while the control phase had no effect.

The reported significance of inferential statistics for the repeated measures ANOVAs remained unchanged when Greenhouse–Geisser corrected.

Control phase

Due to the different testing time-lines across groups (see Table 1), only two cohorts (cohorts 2 and 3) participated in the control phase and were included in the following analyses.

Table 3 reports the regulatory behaviour ($M \pm SE$) during the control phase. The data in Table 3 were entered into a repeated measures analysis of variance, with session as the within-subjects factor. There were no significant effects for any of the regulatory behaviours across sessions, indicating that regulatory behaviour remained stable during the control phase.

Test–retest reliability of the general regulatory questionnaire was calculated using the Pearson correlation coefficient (see Table 3), by correlating (control-1 [baseline] scores with control-3 [2 months] scores). Retest reliabilities were generally over 0.75, with the exception of flossing teeth and sleeping in.

Relationship between VTT and regulatory behaviour

We tested whether the degree of change in VTT performance across the exercise phase predicted the degree of change in regulatory behaviour across the exercise phase. All three cohorts participated in the exercise phase and were included in the analyses. The degree of change was measured using differences across sessions (exercise-3 [2 months] score minus exercise-1 [baseline] score). The difference scores of VTT performance were correlated (Pearson) with the difference scores of general regulatory behaviour (Table 4).

Table 4. Summary of correlations (*r*) between VTT performance and general regulatory behaviour

	VTT difference
Consumption behaviour difference	
Cigarettes ($N = 9$)	0.52**
Alcohol ($N = 18$)	0.48**
Caffeine ($N = 20$)	0.49**
Regulatory behaviour difference	
Junk food ($N = 24$)	0.42**
Healthy habits	0.52**
Impulse spending	0.51**
Over-spending	0.50**
Losing temper	0.44**
Friends instead of study	0.64**
Television instead of study	0.42**
Missing appointments	0.41**
Put off until later	0.43**
Leaving dishes in sink	0.48**
Flossing teeth	0.03
Sleeping in	0.36

**Correlation is significant at the 0.01 level (two-tailed).

As expected the correlations were all significant, with the exception of flossing teeth and sleeping in, suggesting that the VTT and regulatory behaviour questionnaire are measuring something common, which we take to be self-regulation.

Self-reports

Table 5 shows the reported changes in self-efficacy, perceived stress and emotional distress during the exercise phase. Reports of self-efficacy remained stable across sessions. The repeated-measures analysis for the SES showed no effect of session across the exercise phase. Perceived stress decreased during the exercise phase, $F(1, 29) = 38.86$, $p < .001$, as did emotional distress (GHQ), $F(1, 29) = 32.34$, $p < .001$.

Table 5. Emotional responses, means (standard error) in the exercise phase

	Exercise 1	Exercise 2	Exercise 3
PSS	19.3 (1.3)	15.0 (1.2)	9.9 (.66)
GHQ	26.4 (3.4)	20.4 (2.1)	9.8 (1.3)
GSES	29.7 (5.5)	28.2 (7.9)	27.3 (7.3)

Note. The first exercise phase is the same session as the last control phase.

VTT performance (see data in Figure 3) and self-reported regulatory behaviour (see data in Figures 4–6) were also entered into a session (baseline, 1 month, 2 months) × time (before-thought suppression vs. after-thought suppression) repeated measures ANCOVA, with self-efficacy, or perceived stress, or emotional distress as covariates. The effects of mediating variables were not significant. This suggests that the observed improvements in regulatory strength are not due to the effects of exercise on stress, emotional distress or self-efficacy.

Discussion

The main finding to emerge was that the uptake and maintenance of an exercise programme over a 2-month period produced significant improvements in a wide range of regulatory behaviours. The effect was found in both a laboratory task (VTT) and on many self-reported everyday behaviours. The laboratory measure and the self-reported behaviours bore no direct resemblance to the exercise programme, other than that they all involved self-regulation. Participation in the exercise programme improved performance on all the behaviours of interest, except flossing teeth and sleeping habits. In particular, individuals who participated in the exercise programme demonstrated better self-regulation in other spheres: related behaviours (e.g. they engaged in more healthy behaviours), unrelated behaviours (e.g. missed fewer appointments) and laboratory-based performance (visual tracking task).

Previous research has found that regular exertions of self-regulation were followed by improvements in regulatory performance (Muraven *et al.*, 1999; Oaten *et al.*, unpublished data). As expected, in the laboratory task of visual tracking, there was evidence of depletion, as indicated by a deterioration in performance following the thought suppression task in all experimental sessions. This effect of depletion, however, reduced significantly across the exercise phase. This suggests that the uptake and maintenance of the exercise programme made people less vulnerable to the fatiguing effects of regulatory depletion.

Adherence to an exercise programme was also beneficial to a number of other self-regulation operations. A decrease in tobacco, alcohol and caffeine consumption, and an increase in healthy dietary habits, emotional control, maintenance of household chores and self-care habits, attendance to commitments, monitoring of spending, and study habits was observed.

Appropriate controls show that exercise was necessary for regulatory improvement. People on the waiting list to enter the exercise programme showed no changes whatsoever. Thus, while the study sample was self-selected and presumably motivated, this motivation alone was insufficient to produce improved self-regulatory performance. The participants had to actually do the physical exercise for a period of time before any improvements were observed. The fact that regulatory behaviour (laboratory and self-report) was stable during the control phase, and that no participants showed improvement on pre-thought suppression VTT performance across sessions, also indicates that any observed improvement was not an outcome of multiple testing sessions (practice effects), but instead was produced by the adoption of the exercise programme. Furthermore, the self-report data are supported by the objective behavioural measures obtained in the laboratory.

There are some shortcomings in design that need to be acknowledged. The sample was small and our control condition did not utilize experimenter blinding. This is problematic as methodologically weaker studies can show more variation in their outcomes; this is particularly true of smaller studies that can show exaggerated effects when compared with larger samples. Also, longitudinal designs tend to forfeit an element of uniformity. There are, however, several features of the present research that increase confidence in the findings. First, we obtained a 100% rate of participation. This is in part owing to the relatively short duration of the study and to the distribution of diaries that helped to keep participants focused on the exercise programme. The design also required that participants report regularly to the experimenter (experimental sessions, regulatory questionnaire and gymnasium sign-in register). Such interpersonal monitoring may have also influenced participant retention. Second, the self-reported behaviours were reliable (Table 3). Third, improvements in the self-reported behaviours correlated with improvement on the VTT (Table 4). This suggests that the observed improvements in both measures have something in common; we would say the common feature is self-regulation. Along these lines, the measures gain some validity, although such inferences are tentative until further psychometric testing is conducted.

Alternative explanations

The more people do things, the more those things become automatic and habitual. Thus, exercise might become easier as people get into a routine. Were the participants still exerting regulatory effort toward the end of the programme? Diary entries indicate that this was indeed the case. For example, typical comments included: 'I'm enjoying the gym more now that I have a programme . . . but getting there three times a week is a constant struggle', and 'Getting out of bed on time is my biggest hurdle . . . I'd prefer to lie in'. Whilst frequency rates indicated that gym attendance increased, participant comments indicate that such attendance required continued self-regulation.

Past research has found links between success in an exercise programme and improved self-efficacy (McAuley, 1993; Poag & McAuley, 1992). The present study, however, found that participants who engaged in regular exercise did not differ in perceived self-efficacy from individuals on the waiting list. It should be noted that a more domain-specific measure of self-efficacy (e.g. exercise self-efficacy) might have been more sensitive to change. The use of a generalized measure of self-efficacy was, however, congruent with the aims of the present research, and the findings suggest that the observed regulatory improvements cannot be explained by gains in self-efficacy.

There was also a reduction in self-reported perceived stress and emotional distress across the exercise phase. One could make the argument that the exercise itself acts as a stress-reliever, which may account for many of these results. Such arguments, however, cannot explain why engaging in an exercise programme led to more concentration and less distraction on a computer-based task. Furthermore, previous research on exercise does not suggest that it should lead to, for example, better spending habits or less procrastination. Only the idea of building regulatory strength would lead to such a prediction. In other studies that we conducted, regulatory improvements in the absence of reductions in self-reported stress or emotional distress were observed (Oaten & Cheng, 2006; submitted for publication). Therefore, it may well be that improved regulatory strength made these participants better able to manage their stress.

Regular physical activity has all kinds of positive benefits and has been linked to improved mood, resistance to physical fatigue and others (Lawlor & Hopker, 2001; Pollock & Vincent, 1996; White & Sherman, 1999). Any or all of these might generate the observed positive results. Some recent research, however, found that positive mood produced a cost in terms of increased distractibility (Dreisbach & Goschke, 2004). These findings indicate that performance on the laboratory task would be impeded, rather than improved, by the presence of positive mood. It will take a number of studies to unconfound the effects of various possible factors fully. It is worth noting that a similar pattern of results was found after the uptake and maintenance of a study-skills programme and financial monitoring programme (Oaten & Cheng, 2006; submitted for publication).

The findings of the present study have theoretical and practical implications. Theoretically, the findings suggest that our regulatory 'stock' is not set; it can be increased by a number of behaviours. A cornerstone of health education is transmitting information about the diseases associated with lifestyle choices (e.g. knowledge of the link between lack of physical activity and heart disease). We must, however, also translate such knowledge into action. In addition, the action typically requires self-regulation. Therefore, self-regulation is practically implicated in many important personal and societal problems, including over-gambling, abuse of drugs, over-consumption of unhealthy foods, lack of physical exercise, lack of emotional restraint, and failure to adhere to medicinal plans (Baumeister *et al.*, 1994). In an overconsuming society, where food and attractive nonactive leisure activities prevail, perhaps nothing is more important to health than improving self-regulation. It could be a most important 'medicine' for our times.

Acknowledgements

This research was conducted to meet in part the requirements of the Doctor of Philosophy (Psychology) by the first author, under the direction of the second author. The Department of Psychology Postgraduate Research Grant, Macquarie University, supported the first author's work. During the preparation of this manuscript, the second author was a Fellow at the Berlin Institute for Advanced Study, whose support is greatly appreciated.

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Received 22 April 2005; revised version received 9 November 2005