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Self-Regulation and Self-Control in Exercise: The Strength-Energy Model

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Abstract

Self-regulation is an important component of psychosocial theories of exercise behaviour and lack of self-regulatory skills are associated with low adherence to health-related exercise. This review presents a strength-energy model of self-control as an explanation of self-regulation in exercise contexts. The review will provide impetus for original research aimed at understanding exercise behaviour and help develop recommendations for exercise promotion. In the model, self-control is conceptualized as a global but limited resource. Engaging in actions requiring self-control depletes resources leading to self-regulatory failure. Self-control resource depletion is reduced through rest and frequent training on self-control. The expectation of the need to exert self-control in future leads to a conservation of self-control resources. Proposed mechanisms for self-control resource depletion include changes in physiological markers and blood glucose levels. Based on our review, we propose an integrated model of self-regulation incorporating hypotheses from the strength-energy model with those from traditional psychosocial models of exercise behaviour. Recommendations for future research include incorporating hypotheses from the strength-energy model into theories of self-presentation and interpersonal relations in exercise. Practical recommendations aimed at minimising self-control depletion in exercise include the provision of advice on nutrition and recovery, self-control training, and motivational and implementation intention strategies.

Keywords: ego-depletion, limited resource, self-discipline, physical activity, willpower

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Introduction

There is strong evidence that low levels of moderate-to-vigorous exercise are associated with a multitude of health problems (Department of Health, 2004; World Health Organization, 2004). Physical inactivity is an independent correlate of chronic illnesses such as cancer (Byers et al., 2002), cardiovascular disease (Hooper et al., 2001; Williams, 2001), obesity (Ross, Freeman, & Janssen, 2000), and diabetes (Fritz, Wandell, Aberg, & Engfeldt, 2006). Despite this evidence people in both industrialized and developing nations do not engage in sufficient moderate-to-vigorous exercise to gain health benefits (Martin, Morrow, Jackson, & Dunn, 2000) and few meet national guidelines (e.g., Nutrition and Physical Activity Guidelines Advisory Committee, 2001). This is in spite of numerous local, national, and international campaigns and interventions that have sought to increase levels of exercise in the population (e.g., Berkowitz, Huhman, & Nolin, 2008; Huhman et al., 2007; Reger-Nash et al., 2006; Wammes, Oenema, & Brug, 2007). Faced with the public health problems of low exercise levels and increases in associated health conditions, exercise psychologists have endeavoured to identify the key psychosocial correlates of exercise behaviour with the goal of appropriately targeting interventions to achieve successful behaviour change (e.g., Spence & Lee, 2003).

Researchers have identified lapses in self-regulation as an important psychological mediator of numerous health-related behaviours including exercise (Dishman, 1994; Dishman, Ickes, & Morgan, 1980). Self-regulation[1] is defined as the capacity of an individual to exert control over their self (Van Damme, Crombez, Goubert, & Eccleston, 2009). The ability to abstain from gratifying immediate needs and desires is extremely adaptive and enables people to engage in goal-directed behaviour to bring about long-term desirable outcomes (Baumeister, 2005; Mischel, Shoda, & Rodrieguez, 1989). People able to exert self-control over a particular behaviour or action are more likely to be successful in executing that action (Baumeister &

Heatherton, 1996). In contrast, lapses in self-control can result in an inability to adhere to behaviours and actions (Baumeister & Heatherton, 1996). Self-regulatory failure is related to many of the problems and difficulties that people encounter such as excessive personal debt, substance abuse, obesity, unplanned pregnancy and sexually transmitted disease, and crime and violent behaviour (Muraven & Baumeister, 2000). Adherence to exercise constitutes a prime example of a behaviour that requires people to exert self-control, where failure to self-regulate results in lapses in adherence and desistence. In essence, physical inactivity may result from self-regulatory failure. As a consequence, it is important to understand the psychological processes that lead to successful self-regulation and those that lead to its failure. A theory of self-regulation is essential if effective interventions to promote or increase self-regulation and promote adherence to exercise are to be developed.

Traditional approaches to self-regulation in exercise have focused on social cognitive models which contend that people's behaviour is controlled by volitional beliefs, motives, intentions, and expectations with respect to that behaviour (Ajzen, 1991; Ajzen & Fishbein, 1980; Becker, 1974; Rogers, 1975; Triandis, 1977). These approaches suggest that behaviours like exercise require considerable planning and deliberation over goals and outcomes prior to the initiation of the action (Hagger, in press; Hagger & Chatzsiarantis, 2009; Hagger, Chatzisarantis, & Biddle, 2002). Similarly, social learning or skill-based theories suggest that learning behavioural contingencies and developing beliefs about agency from experiences lead to effective self-regulation (Bandura, 1977). In such approaches, people develop self-regulatory skills that provide them with the necessary capacity to engage in the behaviour and cope with contingencies that might impede the behaviour (Bandura, 1995). An alternative approach to self-regulation is proposed in the strength-energy model of self-control. In this model, self-regulation is viewed as a limited resource that is expended when people engage in behaviours that require self-control (Baumeister, Bratslavsky, Muraven, & Tice, 1998;

Muraven & Baumeister, 2000; Muraven, Tice, & Baumeister, 1998). Self-control is therefore defined as a finite resource that becomes depleted after a period of self-control exertion and can only be replenished after a period of recovery or recuperation (Muraven & Baumeister, 2000). Baumeister and colleagues (Baumeister et al., 1998; Baumeister, Muraven, & Tice, 2000; Baumeister, Vohs, & Tice, 2007) use the metaphor of a muscle to describe self-control resource depletion. Just as a muscle loses its strength and becomes fatigued after a period of exertion, so self-control resources become depleted after engaging in actions and behaviours that require self-regulation.

The purpose of the present theoretical review is to evaluate the role of the strength-energy model of self-control in understanding health-related exercise behaviour. The review will begin with an outline of the hypotheses and predictions of the strength-energy model of self-control and its implications for exercise. Specifically, we will outline the main predictions of the limited resource model including methods typically adopted to test the model and the universality of the effect across self-control domains. The salience of self-control strength depletion for the self-regulation of exercise behaviour will be highlighted. Alternative explanations for the limited resource account are also evaluated alongside evidence testing hypotheses from the strength-energy model. We will introduce key moderators of self-control failure and evaluate additional hypotheses of the model which have particular pertinence for exercise behaviour: recovery from self-control resource depletion, the conservation of self-control resources, and the training of self-control capacity. In addition, we propose future directions for research in the area of exercise that arise from the strength-energy model. We will conclude that the strength-energy model provides a useful framework for the understanding self-regulation of exercise behaviour and provides useful practical guidelines for specialists interested in the promotion of exercise adoption and adherence.

The Strength-Energy Model

In contrast to traditional social cognitive theories, the strength-energy model proposes that self-regulation is a universal strength or energy resource that enables people to engage in tasks and actions that require self-control (Baumeister et al., 1998; Muraven et al., 1998). However, the resource is conceptualized as finite and vulnerable to becoming depleted over time. The depletion of self-control resources results in self-regulatory failure such that individuals are no longer able to successfully apply effort to resisting temptations, impulses, and well-learned habits. Baumeister and colleagues (Baumeister et al., 1998; Baumeister et al., 2000; Baumeister et al., 2007) use the analogy of a muscle to describe self-control resource depletion. Just as a muscle requires strength and energy to perform work and becomes fatigued over a period of sustained exertion, individuals can only exert self-control for a limited period and their resources are prone to depletion over time. Similarly, just as muscles require a period of rest or recuperation before further effort can be applied, further application of self-control can only be attained after a period of rest or recuperation. The failure of self-regulation due to the depletion of self-control resources is termed *ego-depletion* (Baumeister et al., 1998).

An important defining characteristic of self-control according to the strength-energy model is that it is a global resource (Baumeister et al., 1998). This means that all actions and behaviours that demand self-control will deplete the resource and the depletion of self-control in one domain will lead to self-regulatory failure in others (Muraven & Baumeister, 2000). Ego-depletion is therefore domain general. People who engage in several tasks that require self-control with no break or period of rest are likely to have their self-control resources depleted (Baumeister et al., 1998). The resultant state of ego-depletion means they will be unable to engage in subsequent tasks that require self-regulation until they have had sufficient opportunity for recovery. For example, an office worker prescribed an exercise regimen by his physician may be asked to write a report at work that is due in at the end of the day. The report requires a large number of laborious calculations and therefore the worker must commit

considerable self-control resources for him to overcome the urge to quit. As he is unable to take a break in order to meet the deadline, it leads to the depletion of his self-regulatory resources. At the end of the day when it comes to participate in his scheduled exercise session, he decides not to go and opts to go for a drink and a meal with friends instead. As predicted by the strength-energy model, the employee avoided engaging in exercise, a task that was likely to demand considerable self-control resources, and was unable to resist the temptation of the more appealing option will little or no self-control demand. Importantly, the reason for his lapse was not physical tiredness, but the depletion of self-control reserves likely manifested in mental fatigue. This example illustrates the premise from the strength-energy model that self-control is a general, global resource which, if depleted in one domain (e.g., the workplace), is likely to lead to self-regulatory failure in others (e.g., exercise).

The ego-depletion effect and predictions of the strength-energy model have typically been tested in experimental designs using a two-task paradigm (Baumeister et al., 1998; Finkel et al., 2006; Muraven et al., 1998). In the procedure, participants are randomly allocated to an experimental ego-depletion group and a no-depletion control group. Depletion group participants are required to engage in an initial task that requires self control. These tasks require participants to resist temptations and impulses or override habitual, well-learned responses. Participants in the no-depletion control group engage in a similar task, but one that does not require self-control. After the first task, participants in both groups are required to engage in a second self-control task, usually in a different domain or sphere of self-control to the first. Performance on the second task is the dependent measure of ego-depletion. The strength-energy model predicts that participants in the ego-depletion group will show a significant decrement in second task performance relative to control participants because their self-control resources were depleted by the initial task.

Baumeister et al. (1998) and Muraven et al. (1998) provided preliminary support for the ego-depletion effect and the strength-energy model in a series of experiments using the two-task paradigm. One experiment was introduced as an ostensible food-tasting test. Participants were presented with two plates of food, one containing appealing cookies and chocolates and the other less-appealing radishes. Participants in the ego-depletion condition were told not to eat the cookies and taste a few of the radishes instead. Resisting the impulse to eat the appealing cookies and eat radishes instead was likely to demand self-control and deplete self-control resources. Participants in the control condition were asked to taste a few of the cookies, an act not deemed to require self-control. After the taste-testing task, all participants were asked to complete as many impossible-to-solve geometric tracing problems as they could. This frustrating task required considerable self-control to resist the temptation to quit. As predicted by the strength-energy model, participants in the ego-depletion (eating radishes) condition spent significantly less time on the problem-solving task compared to participants in the control (eating cookies) condition. The self-control effort that experimental participants had exerted in resisting the tempting foods left them with fewer regulatory resources to commit to solving the problems (Baumeister et al., 1998).

In another study, participants were asked to watch a 3-minute clip of an emotionally-evocative documentary film. Participants were assigned to one of two ego-depletion conditions and asked to complete a handgrip strength task which required them to squeeze a spring-loaded handgrip exerciser for as long as they could. This task demanded self-control because participants had to resist the discomfort in their forearm muscles in order to persist with the task. Participants were then asked to either suppress or exaggerate their emotional responses to the film. In accordance with the strength-energy model, the regulation of emotions requires self control because people have to overcome their innate tendency to freely and proportionately express emotion. Participants assigned to the control (no depletion) condition were asked to

simply watch the video and not given any other instructions. All participants were then asked to perform the handgrip task for a second time. Consistent with the strength-energy model, participants in the depletion groups spent a significantly shorter time on the handgrip task compared to non-depleted controls relative to their baseline performance (Muraven et al., 1998). These studies and others adopting the two-task paradigm provided important preliminary support for the ego-depletion effect.

A considerable body of research adopting the two task paradigm has supported the ego-depletion effect across a diverse range of domains or spheres of self-control (Baumeister, Gailliot, DeWall, & Oaten, 2006; Baumeister & Vohs, 2007; Baumeister et al., 2007; Muraven & Baumeister, 2000). The spheres of task that have been adopted in this literature include: controlling impulses (e.g., resisting tempting foods), controlling thoughts (e.g., suppressing a forbidden thought), controlling emotions (e.g., suppressing emotions toward affectively-evocative stimuli), controlling attention (e.g., naming the typeface colour of a word in a Stroop colour-naming task), making choices (e.g., deciding between two equally-appealing products to buy), applying executive function (e.g., engaging in demanding problem-solving tasks), and engaging in demanding social interactions (e.g., resisting feelings of rejection when ostracised by another). This is unlikely to be a definitive list of the spheres of self-control and research in the field is continually identifying new tasks and behaviours that demand self-control. Importantly, the effect has been shown to be robust across a number of domains of self-control task supporting the hypothesis that the effect is domain general (Baumeister & Vohs, 2007; Baumeister et al., 2007; Hagger, Wood, Stiff, & Chatzisarantis, in press).

Alternatives to the Strength-Energy Model

It is important to consider alternative explanations for the self-regulatory failure. Proposed alternatives include cognitive, cognitive dissonance, emotion, and motivational theories. Research adopting the strength-energy model has suggested that self-control resource

depletion is not a schema a schema or knowledge structure activated through engagement in depleting tasks because performance consistently decreases in the second self-control task and does not improve as would be predicted by a cognitive model (Muraven et al., 1998). Cognitive dissonance theory would predict that the high state of arousal evoked by engaging in an aversive self-control task would compel a change in attitudes towards the task and subsequent improvement. This has been shown to be the case in exercise contexts where advocating engaging in an aversive exercise task promotes changes in attitudes among participants who freely chose to engage in the task (Chatzisarantis, Hagger, & Wang, 2008). However, ego-depletion research adopting the forced-compliance paradigm used in cognitive dissonance theory research found that ego-depletion occurs even in instances where a person chooses to engage in a task that is congruent with his or her attitudes (Baumeister et al., 1998). This suggests that it is the act of choosing rather than dissonance that causes ego-depletion.

The induction of negative affective states and fatigue may provide complimentary explanations for ego-depletion. Tasks and behaviours that require self-control are generally arduous and unpleasant and it would not be surprising if such tasks induced a negative emotional state or mood. Such negative affect would lead to reduced performance as people seek to avoid the aversive emotional state. However, research measuring mood and negative affect after the initial task in ego-depletion experiments generally have found no significant differences in affect between ego-depleted participants and non depleted controls. Even though the active regulation of affect and mood may lead to ego-depletion (Bruyneel, Dewitte, Franses, & Dekimpe, 2009; Muraven et al., 1998), it seems that negative affect and mood do not contribute greatly to the effect. In addition, research has also examined the effect of ego-depletion on self-reported fatigue (e.g., Martijn, Tenbult, Merckelbach, Dreezens, & de Vries, 2002; Muraven et al., 1998). Ego-depletion tasks were found to lead to significantly higher perceptions of subjective depletion such as effort, task difficulty, and self-regulatory fatigue.

Mental fatigue is therefore an analogue for ego-depletion and likely coincides with the depletion of self-control resources.

Traditional models of social cognition might suggest that self-regulatory failure may be due to reduced self-efficacy or motivation on the second task in the two-task paradigm. A self-efficacy explanation would predict that a lack of performance feedback on the initial self-control task may undermine a person's beliefs about their ability to produce outcomes in the second task. To rule out self-efficacy as an explanation, Wallace and Baumeister (2002) manipulated self-efficacy by providing bogus positive and negative feedback on the initial task in the two-task paradigm. Findings indicated significant decrements in second self-control task performance independent of feedback, providing evidence that self-efficacy did not account for the ego-depletion effect. Similarly, a motivational explanation would suggest that the degree of effort a person puts in to the second task would be diminished after the performance of the initial task, perhaps because of the perception that the behaviour will not lead to a desirable outcome. Research measuring self-reported motivation revealed no differences between depleted and non-depleted participants (Muraven, Gagne, & Rosman, 2008). However, providing incentives that increase motivation has overturned the ego-depletion effect. This suggests that motivation may be implicated in the process. Perhaps, self-control resource depletion leads to reduced effort and motivation on subsequent tasks such ego-depletion is akin to an amotivated state. In summary, while cognitive and cognitive alternative explanations have tended not to be supported, negative affect and fatigue may be analogues for a depleted state and reduced motivation may be implicated in the explanation of ego-depletion.

Ego Depletion and Exercise

The limited resource account of self-control provided by the strength-energy model is likely to prove a useful framework for the understanding of self-regulatory failure in the domain of exercise. Research has demonstrated that self-regulatory resource depletion can lead

to reduced participation in exercise (Oaten & Cheng, 2005). Therefore, everyday demands that tax finite self-control resources such as coping with job stress may compromise self-regulatory capacity when it comes to participating in regular health-related exercise (Neubach & Schmidt, 2008; J. C. Wallace, Edwards, Shull, & Finch, 2009). Based on these findings, a key recommendation is that people should not take on too many demanding tasks that require self control at once (Muraven et al., 1998). Self-control resources place a limit on the consecutive activities requiring self-regulation one can accomplish before recovery is required. People prescribing exercise should therefore be mindful of lifestyle factors that might place a strain on self-control resources and plan accordingly. It may be appropriate to make people interested in taking up exercise aware of the potential of their everyday lifestyle demands to impair their efforts to engage in regular exercise. This way people can plan their exercise sessions appropriately for occasions when demands on their self-control resources are relatively light.

Moderators of Ego-Depletion

Numerous moderators of the ego-depletion effect have been identified (Baumeister et al., 2007). In this review, we will confine our discussion to three most pertinent to the study of exercise behaviour: individual differences, motivation, and implementation intentions.

Individual differences in self-control. While the capacity to exert self-control over impulsive or immediately-gratifying actions is considered universal in the self-control model, there may be individual differences in this capacity (Baumeister et al., 2006). Such variations are characterised in trait-level conceptualizations of self-control that propose that people vary in the extent to which they can apply their self-control resources (Cervone, 1996; Metcalfe & Mischel, 1999; Mischel et al., 1989). Tangney and coworkers (2004) developed a psychometric scale to measure trait in self-control and demonstrated that individual differences on this measure was positively associated with a diverse range of adaptive outcomes and responses such as self-esteem, cohesive personal relationships, interpersonal skills, secure attachment,

adaptive emotional profiles, and higher grade point average at college. Trait self control was also negatively associated with maladaptive outcomes such as psychopathology, binge eating, and alcohol abuse. Further research has also demonstrated that trait self-control is associated with adaptive self-regulation in contexts like smoking cessation (Brandon et al., 2003) and self-regulatory failure in domains such as sexual restraint (Gailliot & Baumeister, 2007b) and alcohol abuse (Muraven, Collins, Shiffman, & Paty, 2005). In addition, trait self-control is correlated with individual differences in self-control resource depletion as measured by performance on the behavioural self-control task used in dual-task experiments (Schmeichel & Zell, 2007).

There is also evidence that trait self-control moderates the effect of self-control demands on self-regulation performance (Muraven et al., 2005), although studies have tended to find independent rather than interactive effects for trait and situationally-induced self-control depletion on self-regulatory performance (Gailliot & Baumeister, 2007b; Muraven, Pogarsky, & Shmueli, 2006). The importance of trait self-control is that it identifies people who may be more vulnerable to lapses in self-control. For example, people with low trait self-control who are prescribed exercise regimens would be vulnerable to the depletion of their self-control resources in numerous life contexts (e.g., in the workplace, when studying) and this may have detrimental effects on their ability to engage in their programme of exercise. Overall, it appears that individual differences in self-control capacity exist and that people with high trait self-control are resistant to the deleterious effects of self-regulatory failure.

Motivation. Increasing motivation has been shown to be effective in reducing the deleterious effects of ego-depletion. Numerous strategies have been used in two-task paradigm experiments including promoting the importance of the outcome of tasks and rewards (Muraven & Slessareva, 2003) and fostering self-determined motivation using autonomy-supportive methods (Moller, Deci, & Ryan, 2006; Muraven, 2008; Muraven et al., 2008;

Muraven, Rosman, & Gagne, 2007). The latter strategy shows the most promise from a practical stance because unlike importance and rewards, promoting self-determined reasons for participating in behaviours increases the sense of personal ownership and agency over one's actions. According to self-determination theory, people have an innate desire to be the origin of their behaviour (Deci & Ryan, 2000; Ryan & Deci, 2008). If people engage in a behaviour because it is congruent with their need for autonomy, they are more likely to effectively self-regulate as the behaviour is performed for self-referenced reasons.

In exercise contexts, self-determined motives have been shown to be related to participation (M.S. Hagger & Chatzisarantis, 2007; Ryan, Frederick, Lepes, Rubio, & Sheldon, 1997) and adherence (Edmunds, Ntoumanis, & Duda, 2007; Fortier & Kowal, 2007). Autonomy support may therefore be effective in overcoming lapses in self-regulation and provide an impetus for people to draw further from their self-control resources (Ryan & Deci, 2008). However, given that self-control resources are ultimately finite, the strength-energy model predicts that motivation may only temporarily stave off the effects of ego-depletion and eventually the fatigue will become insurmountable (Baumeister et al., 2007). No research to date has investigated this boundary condition and more work is needed to ascertain the extent to which motivation can help overcome self-regulatory failure. Exercise specialists should therefore attempt to foster self-determined motives for engaging in exercise (Chatzisarantis & Hagger, 2007). Autonomy-supportive strategies include providing a rationale for initiating exercise, providing choice over activities, and encouraging the development of self-referenced reasons for exercising (Chatzisarantis & Hagger, 2009; Reeve & Jang, 2006). Furthermore, exercise promoters should provide an acknowledgment of the difficulties and conflicts involved in engaging in exercise (Markland, Ryan, Tobin, & Rollnick, 2005; Markland & Vansteenkiste, 2007; Vansteenkiste & Sheldon, 2006).

Implementation Intentions. Another strategy that has been shown to overcome ego-depletion is implementation intentions. Implementation intentions are action plans that increase the likelihood of people carrying out their intended actions and are often framed as 'if-then' plans (Gollwitzer, 1999; Gollwitzer & Sheeran, 2006). Such plans highlight the pertinent cues likely to assist in the recall and efficient enactment of intentions (Brandstätter, Lengfelder, & Gollwitzer, 2001; Webb & Sheeran, 2008). As engaging in a program of regular exercise requires considerable self-control, implementation intentions may be an effective strategy to prevent lapses in adherence due to self-regulatory failure. Those involved in promoting exercise are therefore advised to encourage people to form implementation intentions as part of their behaviour-change advice. Implementation intentions are most effective if the actor explicitly specifies an environmental cue such as a time and a place (e.g., "at 5pm after work") and the action (e.g., "pick up my gym bag and walk to the gym") rather than a global plan (Chapman, Armitage, & Norman, 2009). It is also important that the plan is self-generated, involves significant others, and is written down (Orbell, Hodgkins, & Sheeran, 1997; Prestwich et al., 2005). Studies have also advocated the use of mobile telephone text messages as a means to remind people of their cues to act (Prestwich, Perugini, & Hurling, 2009). Research has also demonstrated that implementations intentions are more likely be effective if they are combined with motivational strategies (Chatzisarantis, Hagger, & Thøgersen-Ntoumani, 2008; Koestner et al., 2006; Milne, Orbell, & Sheeran, 2002; Prestwich, Lawton, & Conner, 2003). These hybrid interventions are likely to be effective in changing exercise intentions and increasing the relationship between intentions and exercise behaviour by increasing people's propensity to allocate self-control resources in the pursuit of the behaviour.

Extending the Strength-Energy Model

The Conservation Hypothesis

As mentioned previously, the strength-energy model proposes that engaging in self-control tasks results in a partial depletion of self-control resources. Although there is scope for individuals to tap further into their precious reserves, the conservation of such resources for times of need is an adaptive response in order to maximise economy. Empirical tests of the conservation of self-control resources have introduced an additional manipulation in the two-task paradigm informing participants that they would engage in an additional self-control task after the second task (Muraven, Shmueli, & Burkley, 2006; Tyler & Burns, 2009). As predicted by the conservation hypothesis, participants told to expect future demand on their self-control resources performed significantly worse on the second self-control task compared to depletion participants who did not expect to exert self-control in the future.

This is important with respect to people attempting to modify their exercise behaviour. If people have had a recent demand for self-regulatory resources and anticipate high future demand such as deadlines at work or university, they are likely to attempt to conserve their self-control by avoiding other activities likely tax these resources, such as their exercise regimen. Some preliminary evidence has been found in support of this premise. Oaten and Cheng (2005) demonstrated that University students reported significantly lower levels of exercise during examination periods compared with periods where there were no exams. This was corroborated by other indices of self-regulatory failure during exam time such as significant increases in smoking and alcohol intake and impaired performance on laboratory self-control tasks such as the Stroop task.

The Recovery Hypothesis

One of the fundamental implications of the conceptualization of self-control as a limited resource is that a period of rest or relaxation will lead to the replenishment of the resource (Muraven & Baumeister, 2000). Returning to the muscle analogy, a period of rest or recuperation is required for fatigued muscles to regain their former strength. Similarly,

following the depletion of self-control resources, a sufficient recovery period is necessary for full self-regulatory capacity to be restored. Support for the recovery hypothesis has been gleaned from studies that have introduced a period of rest or relaxation between the initial and second tasks in the two-task paradigm (Oaten, Williams, Jones, & Zadro, 2008; Tyler & Burns, 2008). Tyler and Burns (2008) demonstrated that for brief self-control tasks, self-regulatory capacity is almost completely restored after a 10-minute break, with partial restoration achieved after 3-minutes. For more prolonged initial depleting tasks, Oaten et al. (2008) found that a 45-minute break only resulted in partial recovery. Together, these results indicate a 'dose' effect for recovery with shorter recovery only resulting in partial replenishment and a period of rest proportional to the duration of the depleting task necessary for full recovery. This has relevant implications for people attempting to adhere to exercise programs. It is important that prospective exercisers are advised to take sufficient breaks and get enough sleep. This will not only permit physiological recovery but will also ensure replenishment of self-control resources. In addition, the duration of the recovery spell relative to the self-control demands of the depleting task is a consideration. There is some evidence to suggest that recovery is more complete when a longer period of recovery is given (Tyler & Burns, 2008). In an exercise context, it is therefore important to take into account the duration and intensity of the exercise when considering the amount of time required to fully restore self-control resources. Fully replenished self-control resources will maximise the probability that the exerciser will be able to exert self-control to engage in the next exercise session.

The recovery hypothesis highlights the importance of scheduling sufficient breaks to rest and fully recover self-control resources for people attempting to incorporate exercise into their daily routines. Research has demonstrated the effectiveness of even short breaks on the recovery of self-control capacity (Tyler & Burns, 2008). Regular breaks are therefore an important part of maintaining self-control strength and minimising vulnerability to ego-

depletion. In addition, getting sufficient sleep is also important to maintain self-control strength (Barber, Munz, Bagsby, & Powell, in press; Baumeister, 2003). Compromised sleep patterns and sleep deprivation are associated with decreased cognitive functioning including deficits in performance on memory and vigilance tasks (Altena, Van Der Werf, Strijers, & Van Someren, 2008; Walker, 2008). Although no study has formally examined the effect of sleep deprivation on the replenishment of self-control resources, consistent with the recovery hypothesis getting sufficient sleep should be an important contributory factor to effective self-regulatory performance. People involved in the prescription of exercise routines and the design of campaigns promoting exercise should therefore provide information on the importance of rest and sleep. This will aid the replenishment of self-control resources depleted through everyday stress and pressures and, in turn, reduce people's vulnerability to lapses in exercise adherence.

The Training Hypothesis

One of the more intriguing possibilities presented by the strength-energy model is the hypothesis that people can improve their self-control capacity by engaging in a regular program of practice or training on self-control tasks. Just as a muscle can improve its strength and endurance through regular training, frequent engagement in tasks that require self-control is expected to lead to improvements in self control. Importantly, given that self-control is domain general, training on self-control tasks in one domain is likely to lead to improved self-regulatory capacity in others. Experimental research has shown that regular engagement in tasks that demand self-control such as using the non-dominant hand to perform everyday tasks, modifying speech (e.g., avoiding use of colloquialisms), controlling emotions, modifying posture, monitoring diet, and regular use of an aversive mouthwash can lead to increased exercise adherence (Gailliot, Plant, Butz, & Baumeister, 2007; Hui, Wright, Simmons, Eaton, & Nolte, in submission; Muraven, Baumeister, & Tice, 1999; Oaten & Cheng, 2006a). Field research has also demonstrated that long-term practice on self-control tasks such as engaging in

a regular programme of academic study also results in significant increases in exercise participation (Oaten & Cheng, 2006a). Taken together, these findings are consistent with the strength-energy model. Just as the act of engaging in the self-control required to engage in a regular program of exercise improves self-control (Oaten & Cheng, 2006b), other activities that require self-control can help improve exercise participation.

Advocating training on such tasks may be useful advice for exercise promoters to provide when giving advice regarding changing exercise behaviour. For example, behaviours that have been shown to be effective in training self-control capacity include monitoring dietary intake using food diaries and avoiding foods high in fat. Such activities are likely to be acceptable to the advisee if presented alongside exercise as part of a general lifestyle change program because they have good-fit with a general health agendum. As an offshoot, encouraging these self-regulatory behaviours may also bring about additional adaptive changes in health outcomes. Exercise promoters should therefore encourage people in the early stages of an exercise programme to adopt these additional behaviours concurrent to the exercise regimen.

However, it is probably prudent to delay the introduction of these additional behaviours when people are in the very early stages of an exercise programme. Taking on too many self-control tasks at once may lead to short-term overload of self-control resources resulting in self-regulatory failure and premature drop out. It is also important that those involved with prescribing exercise are aware of the relative demands on self-control resources for people at different stages of exercise adoption. Those who are just introducing exercise into their lifestyle are likely to have greater demands on their self-control resources as they have to engage in considerably more effort in planning their activity and are likely to have more barriers to overcome. Those who have made changes and have been exercising regularly for a while will have fewer, although certainly not negligible, demands. Furthermore, the previous

exertion of self-control through adhering to their exercise routine is also likely to improve the self-control strength of these people through the training effect. Therefore, if a person decides to initiate several health-related behaviours that require self-control simultaneously, he/she is likely to be vulnerable to ego-depletion as he/she will have an excessive demand on self-control resources and may fail to persist in regulating some of all of the demanding behaviours. However, if he/she staggers the initiation of these behaviours by introducing them progressively one at a time then there are less likely to be such excessive demands of self-control resources. This is because he/she may 'build up' self-control strength through the training of his/her self-control capacity by the first-introduced behaviours. This increased strength may provide the additional resources to successfully regulate behaviour when additional health-related behaviours are introduced.

Mechanisms of Ego-Depletion

Physiological Responses to Ego-Depletion

In developing the strength-energy model, Baumeister et al. (1998) proposed that it was unlikely that there would be no physiological component to the mechanism behind ego-depletion. This proposal has been corroborated in research examining the physiological mediators of self-regulatory resource depletion. For example, Bray et al. (2008) found that participants whose self-regulatory resources were depleted by completing an incongruent Stroop colour-naming task exhibited significantly higher electromyographic activity when performing a subsequent physical (hand grip strength) task compared to non-depleted controls. This indicates that ego-depleted individuals have to recruit a larger number of muscle fibres to perform the same amount of work as non-depleted individuals. This has been supported by research that has shown increases in physiological parameters associated with effort among ego-depleted individuals. These physiological analogues for increased self-regulatory effort under ego-depletion include heart rate variability (Segerstrom & Nes, 2007) and blood pressure

(Wright et al., 2007; Wright, Martin, & Bland, 2003; Wright, Stewart, & Barnett, 2008). These findings have been married with increased electroencephalographic activity in brain areas associated with effort (Inzlicht & Gutsell, 2007). There is therefore preliminary evidence for the physiological consequences of ego-depletion and support for the premise of the strength-energy model that self-control in depleted individuals requires increased effort.

Glucose and Self-Control Resource Depletion

A recent development in the field has demonstrated that self-regulatory failure is coupled with decreases in the supply of glucose to the brain (Dvorak & Simons, 2009; Gailliot & Baumeister, 2007a; Masicampo & Baumeister, 2008). Galliot et al. (2007) measured the blood glucose levels of participants engaging in self-control tasks in the two-task paradigm. Results revealed significant decreases in blood glucose after the initial self-control task but no changes in the blood glucose of control participants. Similarly, providing people with a glucose drink between tasks tended to mitigate the ego-depletion effect (DeWall, Baumeister, Gailliot, & Maner, 2008; Gailliot, Baumeister et al., 2007; Gailliot, Peruche, Plant, & Baumeister, 2009; Masicampo & Baumeister, 2008).

These findings have important implications for people's ability to self-regulate. People with inadequate blood glucose supply may find it difficult to engage in activities and behaviours that require self-regulation. Although glucose levels in the brain tend to be maintained at relatively constant levels even when blood glucose levels are depressed, lowered blood glucose coincides with ego-depletion, perhaps due to its role in leading central fatigue and general motivation to reduce effort on tasks to conserve energy. Indeed, psychophysiological research demonstrates that although lower blood glucose does not lead to impaired performance on cognitive tasks (Green, Elliman, & Rogers, 1997; Lieberman et al., 2008), it is implicated in subjective fatigue and the ingestion of glucose leads to increased performance on cognitive tasks (Hoyland, Lawton, & Dye, 2008). As a practical example, a

businesswoman prescribed a health-related exercise program may have the occasion of a busy day at work and decides to skip lunch to keep on schedule. This may compromise blood glucose levels which may promote central fatigue so that when it comes to follow her prescribed exercise routine at the end of the day, she lacks self-regulatory strength and fails to resist the urge to avoid the effort of exercising.

It is therefore important to consider glucose as a factor when attempting to engage in behaviours that require consistent self-regulatory effort such as adhering to an exercise program. This may also apply to people involved in important interactions relating to their exercise or sport. For example, reduced blood glucose may be implicated in failure to maintain harmonious interpersonal relationships between athletes and coaches and in aggressive displays and indiscipline in athletes. Given that exercise and sport places a high demand on the physiological system, it is important that exercisers and athletes take in sufficient carbohydrate not only to fuel their muscles but also to maintain adequate blood glucose levels. The maintenance of glucose levels may prevent increased perceptions of fatigue and lapses in self-control that could lead to failure to adhere in exercisers or fractious relationships or aggression in athletes. Exercise specialists, coaches, and sports trainers therefore have an obligation to encourage their wards to eat small, frequent meals to maintain blood glucose.

Recent nutritional advice suggests that the type of food may also be important in this regard. Low glycaemic index (GI) foods have been shown to provide sustained release of glucose into the bloodstream (Radulian, Rusu, Dragomir, & Posea, 2009). Such foods may be the most effective in maintaining constant blood glucose levels thereby minimising central fatigue and promoting self-control resource availability. There is evidence to suggest that ingestion of low-GI foods may be effective in maintaining cognitive performance (Gilsenan, de Bruin, & Dye, 2009). High GI foods are likely to provide sufficient energy to increase blood glucose levels temporarily, but they may subsequently lead to a sharp drop in blood glucose

and exacerbate the problem. Therefore nutritional advice to exercisers and athletes should be to consume low GI foods regularly for optimal maintenance of blood glucose levels. They should also be advised not to snack on high GI foods for a quick 'energy fix' and instead opt for foods that are unlikely to cause rapid fluctuations in blood glucose. Following these guidelines will contribute to the maintenance of constant blood glucose levels and prevent self-regulatory resource depletion caused by lack of glucose supply to the brain

Implications for Theory Development and Future Research

Integrating the Strength-Energy Model with Other Models of Exercise Behaviour

The present review has outlined the key hypotheses of the strength-energy model, and highlighted the deleterious effects of self-regulatory failure for individuals attempting to change their exercise behaviour or adhere to an exercise program. The effect of self-regulatory resource depletion has also been shown to be independent of cognitive schema and other explanations. However, it is important to examine how this model may be integrated with existing models of self-regulation and whether it can offer new insight into the understanding of the antecedents and mechanisms that underpin exercise adherence (Hagger, 2009, in press). Traditional models of self-regulation such as the theories of reasoned action and planned behaviour view behavioural engagement as a function of intentions or plans to engage in exercise (Ajzen, 1991; Ajzen & Fishbein, 1980). As cited earlier, a problem of these theories is that the link between intention and behaviour is imperfect (Hagger et al., 2002), which means that changing intentions does not lead to a direct unit-change in behaviour (Webb & Sheeran, 2006). One reason for this imperfect link may be people's low self-regulatory resources. The strength-energy model predicts that self-regulatory capacity is maximised when self-control resources are high. Given that exercise is a planned behaviour that demands disciplined self-regulatory effort to plan the activity and perform the actions and behaviours involved (McLachlan & Hagger, in press; Sniehotta, Scholz, & Schwarzer, 2005). Accordingly, it

follows that people will be more likely to enact their intentions if they have sufficient self-control resources. This suggests that self-control capacity will moderate the intention-behaviour relationship and should be included as an additional variable in such models.

There is preliminary evidence providing support for the inclusion of self-control depletion as a moderator in psychosocial models of behaviour. Muraven, Collins, Shiffman, and Paty (2005) found that people with high intentions to stem their alcohol intake were more susceptible to the depletion of self-control resources from daily demands and were more likely to consume alcohol above their self-imposed limit. People who intend to engage in behaviours that require self-regulation are, therefore, susceptible to self-regulatory resource depletion. This corroborates the hypothesis that people who intend to engage in exercise are vulnerable to self-control resource depletion and therefore require sufficient resources to maintain their behaviour. However, to date, no research has been formally conducted to examine this effect in an exercise context, and future work is needed to support this integration.

The inclusion of self-control as a limited resource in traditional psychosocial models of behaviour may also provide some insight into the processes involved. As highlighted in the present review, self-control capacity has been conceptualized both as the situational status of self-control resources and as an individual difference that reflects one's general capacity to self-regulate behaviour in many domains (Baumeister et al., 2006)[2]. Making this distinction in research integrating self-control resource capacity into the theory of planned behaviour may be useful. The theory of planned behaviour proposes that behaviour is a function of intentions and beliefs with respect to future behavioural engagement (Ajzen, 1991). As such, situational self-control capacity may be relevant when making such decisions. However, researchers incorporating personality and trait-like constructs within the theory have demonstrated that such variables act as distal influences on the decision-making components of the theory (Conner & Abraham, 2001; Hagger, Chatzisarantis, & Harris, 2006; Rhodes, Courneya, &

Jones, 2002). In addition, research has also demonstrated that individual difference constructs predict behaviour directly (Rhodes & Courneya, 2003). Such effects are likely to reflect the more impulsive, non-deliberative processes that result in behavioural engagement as specified recently in dual-route models of social behaviour (Hofmann, Friese, & Wiers, 2008; Strack & Deutsch, 2004). Self-control may therefore have multiple effects on behaviour in such models. While state self-control may moderate the intention-behaviour relationship, trait self-control may also be an independent predictor of intentions or have a direct influence on behaviour.

Precedence for this comes from recent research by Hoyt, Rhodes, Hausenblas, and Giacobbi (2009) who demonstrated that the *self-discipline* facet of conscientiousness was an independent predictor of exercise intentions but not behaviour. Self-discipline did not moderate the intention-behaviour relationship. These findings suggest that individual differences in self-discipline is a distal predictor of exercise intentions, such that those high in self-discipline are more likely to form intentions to exercise and are more likely to engage in exercise behaviour through this route. Future research needs to study these effects in more detail by formally adopting the strength-energy model and directly relevant measures such as behavioural measures of state self-control and Tangney et al.'s (2004) trait measure.

Integrating Self-Control into Self-Theories

Self-control resource depletion has been shown to be associated with behaviours relating to appearance and the presentation of the self. Vohs et al. (2005) conducted a series of studies to demonstrate that the act of presenting the self to project a certain impression demanded self-control and engaging in self-presentational tasks resulted in self-regulatory resource depletion. For example, people who were required to present themselves as boastful to friends and modest to strangers or to make a persuasive speech to a sceptical audience showed significant decrements in self-control performance using the two-task paradigm. This is unsurprising as engaging in such impression management demands a high degree of self-

control and requires one to override the well-learned behaviours typically displayed in these contexts.

In exercise contexts, high social physique anxiety levels, a self-presentational construct that reflects an individual's concern with presenting a negative view of the physical self to others, are related to motivation to avoid exercising in such contexts to minimise negative self-presentation (Kowalski, Crocker, & Kowalski, 2001) and maladaptive outcomes such as eating disordered behaviours (Haase & Prapavessis, 1998; Hausenblas & Mack, 1999) and low self-esteem (Hagger, Hein, & Chatzisarantis, in press; Hagger & Stevenson, in press). Research has also shown negative relations between attitudes towards exercise and social physique anxiety for people acting in evaluative settings such as exercising in clothing that emphasises the physique and environments that draw attention to the physique such as mirrored exercise classrooms (Crawford & Eklund, 1994). It is therefore likely that people with high social physique anxiety who attend exercise classes in an environment perceived as evaluative will be vulnerable to self-control resource depletion. This is because they have to overcome the motivation to avoid the aversive exercise context. If the person's self-regulatory resources were depleted before they were due to engage in the class, the strength-energy model predicts that they may be unlikely to attend because they were unable to resist the motivation to avoid that situation. This is an important future avenue for research because it will provide new insight in the mechanisms behind self-presentation and exercise behaviour.

Interpersonal Relations and Self-Control

Maintaining harmonious and high-functioning personal relationships is also an important domain that demands self-control. Research adopting the strength-energy model has shown that ego-depleted people are more likely to respond destructively and less likely to be accommodating in close personal relationships (Finkel & Campbell, 2001). Self-regulatory resource depletion is also linked to lowered ability to pick up important social cues that foster

good interpersonal relationships (Tyler, 2008). In addition, trait self-control has been shown to be significantly and positively related to various indicators of adaptive personal relations such as family cohesion, secure attachment, perspective taking, empathic concern, and accommodative behaviours (Finkel & Campbell, 2001; Tangney et al., 2004). People who regularly engage in demanding social interactions are likely to have a heavy demand on their self-regulatory resources and thus be prone to self-regulatory failure in other contexts. This may have implications for people's ability to adhere to an exercise program, as outlined previously. This also has implications for people who need to interact with people about their exercise. For example, people referred to exercise specialists often need to go to several sessions in order to investigate their reasons for change and develop an exercise program. One of the largest obstacles in such sessions is the 'psychological resistance' that individuals have to changing their lifestyle. Although exercise specialists are often taught how to counter this resistance using motivational interviewing techniques (Rollnick & Miller, 1995), such resistance may be exacerbated in individuals who have low self-regulatory capacity due to resource depletion in other spheres. Exercise specialists should therefore be aware of potential conflicts and resistance in their patients due to low self-regulatory capacity.

The link between ego-depletion and reduced ability to maintain effective social relationships may also have implications for those exercising in more competitive arenas. Research has consistently demonstrated the importance effective relationships between coaches and their athletes and the positive effect such relationships have on team cohesion and outcomes (Jowett & Chaundy, 2004; Jowett & Clark-Carter, 2006). However, when this relationship breaks down it can have detrimental effects on performance outcomes of athlete. One reason for this breakdown may be due to the depletion of self-regulatory strength. If coaches or athletes have been compelled to exert self-control in another domain that depletes their self-control resources, perhaps when dealing with other people (e.g., media interviews) or

when they have examinations or tests in education settings (e.g., young athletes in school, students and coaches studying to obtain coaching qualifications), then they may be less likely to be accommodating and more likely to engage in interpersonal conflict. Therefore rather than engaging in collaborative thinking and agreeing goals and practices, the depletion of resources may lead to increased conflict in coach-athlete interactions.

Other interpersonal problems in the sport domain may also be related to self-control resource depletion. Indiscipline and aggression among sports participants can occur quite frequently, despite such behaviours being detrimental to the overall goals and aims of the individual sports performer and his or her team (Widmeyer, Bray, Dorsch, & McGuire, 2001). Sports participants may become frustrated because they do not perform to expectations or view a certain refereeing decision as an injustice. They may therefore react violently or aggress in an attempt at retribution. The individual may be penalised, dismissed, or disqualified as a result of rule infringements caused by the indiscipline or aggressive display. Given research linking trait self-control with increased propensity to express anger (Tangney et al., 2004) and lowered state self-regulatory resources with increased aggressive behaviour (DeWall, Baumeister, Stillman, & Gailliot, 2007; Stucke & Baumeister, 2006), such counterproductive aggressive behaviours in the domain of sport may be the result of low self-control resources. According to the strength-energy model, the depletion of self-control resources in other domains may leave sport participants with insufficient self-regulatory strength to resist the urge to lash out in response to a perceived injustice or frustration over poor performance. The strength-energy model may therefore provide an explanation for lapses in discipline and lack of restraint in sports participants.

Integrated Physiological Models of Ego-Depletion

Given the findings that ego-depletion leads to concomitant changes in physiological parameters like heart rate variability (Segerstrom & Nes, 2007) and blood pressure (Wright et

al., 2007; Wright et al., 2003; Wright et al., 2008), psychophysiological indices of effort like electromyographic (Bray et al., 2008) and electroencephalographic (Inzlicht & Gutsell, 2007) activity, and blood glucose levels (Gailliot & Baumeister, 2007a; Gailliot, Baumeister et al., 2007; Gailliot et al., 2009), researchers have called for future research that formally combines these measures to provide a unified psychophysiological account for self-regulatory resource depletion (Bray et al., 2008). Integrating the findings for glucose depletion and supplementation with those for the physiological indicators of self-regulatory effort will provide an important account of the processes and mechanisms behind the ego-depletion effect. To date, no study has adopted measures of blood glucose and glucose supplementation alongside analogues of physiological effort to investigate the ego-depletion effect.

Conclusion

Successful adherence to exercise has been shown to be a function of self-regulation with failure to self-regulate implicated in desistence and drop out from exercise programs. The strength-energy model provides a general framework for the understanding of self-regulatory failure in the exercise domain. The model conceptualizes self-regulation as a global limited resource, depletion of which leads to self-regulatory failure. In the present article, we have reviewed the empirical research on self-regulatory resource depletion and explored the effectiveness of the strength-energy model as a framework to understand exercise behaviour. We reviewed the recovery, conservation, and training hypotheses in the model and identified key moderators of self-control resource failure: trait self-control, motivation, and implementation intentions. Consideration was also given to the mechanisms behind self-control resource depletion including physiological analogues and glucose depletion and supplementation. The theoretical overview and supporting empirical research has allowed us to make original insights into the processes by which self-regulation affects exercise behaviour

and propose new integrated theoretical models incorporating hypotheses from the strength-energy model and those from traditional social-cognitive approaches.

Practical recommendations for the promotion of exercise have also emerged from our review. We recommend exercise promoters encourage people to initiate exercise programs at times when they have few demands on their self-regulatory resources. Strategies to maximise self-regulatory capacity such as getting appropriate nutrition and sufficient sleep should also be advocated. We also recommend the gradual introduction of other means to bolster self-regulatory capacity such as dietary self-monitoring. It is important to note that although the strength-energy model offers considerable promise to understand behaviour in exercise contexts, there is a relative dearth of research applying the model in such contexts. The recommendations outlined in the present review represent speculations based on the hypotheses of the strength-energy model of self-control and empirical tests of such hypotheses in other domains and for other behaviours that match the self-regulation demands of exercise. In particular, future research needs to provide formal corroboration of the conservation and recovery hypotheses in exercise contexts, examine differential roles of trait and situationally-induced self-control in the context of other psychosocial models of exercise behaviour, and test the effectiveness of motivational and implementation intentions in reducing self-regulatory failure in exercise.

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Footnote

[1]In the present article we refer to self-control and self-regulation interchangeably. In the context of the strength-energy model, this is the norm. Authors who do make a distinction regard self-regulation as a global term referring to the ability to exert control over all responses and behaviors as well as the regulation of physiological responses. Self-control is viewed as a more specific form of self-regulation defined as control over behaviors and outcomes.

[2]It is important to note that both state and trait self-control capacity must be considered domain general and are relevant to self-regulation across a diverse range of behavioural domains. Just because state self-control is likely to be a function of situational factors (e.g., recent performance of tasks or behaviours requiring self-control), it does not mean that an acute depletion of self-control resources is confined to that behavioural domain. Indeed, a key hypothesis of the strength-energy model is the domain generality of the effect and the large body of research on the two-task paradigm has provided corroboratory evidence for this. Rather, the distinction should be made clear that state self-control capacity is less stable and more subject to change than trait self-control. Trait self-control capacity may be an influential factor on acute self-control resource depletion, but the latter is also subject to situational factors.