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A single bout of resistance exercise can enhance episodic memory performance

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ABSTRACT

Acute aerobic exercise can be beneficial to episodic memory. This benefit may occur because exercise produces a similar physiological response as physical stressors. When administered during consolidation, acute stress, both physical and psychological, consistently enhances episodic memory, particularly memory for emotional materials. Here we investigated whether a single bout of resistance exercise performed during consolidation can produce episodic memory benefits 48 h later. We used a one-leg knee extension/flexion task for the resistance exercise. To assess the physiological response to the exercise, we measured salivary alpha amylase (a biomarker of central norepinephrine), heart rate, and blood pressure. To test emotional episodic memory, we used a remember-know recognition memory paradigm with equal numbers of positive, negative, and neutral IAPS images as stimuli. The group that performed the exercise, the active group, had higher overall recognition accuracy than the group that did not exercise, the passive group. We found a robust effect of valence across groups, with better performance on emotional items as compared to neutral items and no difference between positive and negative items. This effect changed based on the physiological response to the exercise. Within the active group, participants with a high physiological response to the exercise were impaired for neutral items as compared to participants with a low physiological response to the exercise. Our results demonstrate that a single bout of resistance exercise performed during consolidation can enhance episodic memory and that the effect of valence on memory depends on the physiological response to the exercise.

1. Introduction

Studies examining the effects of exercise on cognition have focused on two types of exercise: aerobic and resistance exercises. Aerobic exercise refers to activities that involve large muscle groups and cause your body to increase its oxygen use. Examples of aerobic exercise include running, bicycling, and swimming. In contrast to aerobic exercise, resistance exercise does not increase oxygen use. Resistance exercise improves muscle tone, bone strength, balance, and coordination. Examples of resistance exercise include weightlifting, push-ups, and sit-ups. Both aerobic and resistance exercises are important for physical health, and both have been linked to cognitive benefits.

Long-term aerobic exercise interventions are associated with broad cognitive benefits (Dresler et al., 2013), including episodic memory (Kattenstroth, Kalisch, Holt, Tegenthoff, & Dinse, 2013). In addition, evidence suggests that resistance exercise training can improve episodic memory performance and executive functioning (Liu-Ambrose, Nagamatsu, Voss, Khan, & Handy, 2012; Voss, Nagamatsu, Liu-Ambrose, & Kramer, 2011). A variety of exercise regimens have been used to show these benefits, from traditional exercise to exergaming (Anderson-Hanley et al., 2012; Best, 2013) to dance (Coubard, Duretz, Lefebvre, Lapalus, & Ferrufino, 2011; Kattenstroth, Kalisch, Holt, Tegenthoff & Dinse, 2013). Overall, there is widespread agreement that various kinds of long-term exercise can improve cognitive function across the lifespan.

Single bouts of aerobic exercise after learning can also produce episodic memory improvements in young adults. For example, performance on recall tests (Labban & Etnier, 2011; Salas, Minakata, & Kelemen, 2011), face–name matching (Griffin et al., 2011), and paired associates learning (Nanda, Balde, & Manjunatha, 2013; Schmidt-Kassow et al., 2013; Winter et al., 2007) improve following a single bout of moderate aerobic exercise. Interestingly, high intensity exercise may impair subsequent recall (Eich & Metcalfe, 2009). These studies provide evidence that single bouts of moderate intensity aerobic exercise can be beneficial to episodic memory.

One reason why a single bout of exercise can yield cognitive benefits is that exercise is a physical stressor (Mastorakos, Pavlatou, Diamanti-Kandarakis, & Chrousos, 2005) and stressors have been shown to

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facilitate cognition under certain circumstances, as discussed below. Stressors result in the secretion of neuroendocrine mediators, which can be split into an initial rapid response from the sympathetic nervous system resulting in epinephrine and norepinephrine release and a slower response from the hypothalamic–pituitary–adrenal (HPA) axis resulting in cortisol release (for review, see Wolf, 2008). Increases in cortisol have been observed following both acute aerobic exercise (Fryer et al., 2012; Labsy et al., 2013; Usui et al., 2011; VanBruggen, Hackney, McMurray, & Ondrak, 2011; Wahl, Zinner, Achtzehn, Bloch, & Mester, 2010) and resistance exercise (Cadore et al., 2012; Hough, Papacosta, Wraith, & Gleeson, 2011; Leite et al., 2011; Pledge, Grosset, & Onambele-Pearson, 2011; Szivak et al., 2013; Uchida et al., 2009).

The beneficial effects of acute stress during consolidation on episodic memory have been demonstrated using both physical and psychological stressors. The cold pressor test (CPT) requires participants to hold one hand submerged in cold water for several minutes. Exposure to CPT immediately after learning can increase recall (Cahill, Gorski, & Le, 2003; Schwabe, Bohringer, Chatterjee, & Schachinger, 2008; Smeets, Otgaar, Candel & Wolf, 2008). A similar finding (Payne et al., 2006; Preuss & Wolf, 2009; Smeets, Giesbrecht, Jelicic, & Merckelbach, 2007) has been observed for the Trier Social Stress Test (TSST), a psychological stressor that requires participants to give a brief speech in the presence of others and perform a mental arithmetic task (Kirschbaum, Pirke, & Hellhammer, 1993). The benefits of these acute stressors emerge when the stress occurs during consolidation, defined as the period immediately following encoding (for review, see Wolf, 2008). Evidence suggests that the emotional valence of the to-be-remembered material changes the effect of stress on memory. There is evidence that stress selectively enhances emotional memory (Payne et al., 2007; Smeets, Otgaar, Candel, & Wolf, 2008) as well as evidence that stress selectively impairs neutral information (Payne et al., 2006).

The memory benefits resulting from stress induction are believed to be due to the effect of stress hormones (i.e., cortisol and epinephrine) on interactions between the amygdala and hippocampus; thereby enhancing consolidation of emotionally arousing materials (for review, see Roozendaal, McEwen, & Chattarji, 2009). Epinephrine, which is secreted from the adrenal medulla, induces the release of norepinephrine in the basolateral amygdala (BLA) by activating vagal afferents to the nucleus of the solitary tract (McGaugh & Roozendaal, 2002). In support of this idea, salivary measures of alpha amylase (AA), a marker of central norepinephrine, (van Stegeren, Rohleder, Everaerd, & Wolf, 2006) positively correlate with emotional memory performance. Cortisol also has been shown to positively correlate with the amount of emotional information remembered following CPT administration (Smeets et al., 2008). Exogenous administration of stress hormones also selectively enhances memory for emotional information (Segal & Cahill, 2009). Because a single bout of exercise produces the same kind of physiological responses, including increases in cortisol and norepinephrine, it is reasonable to predict that exercise during consolidation will improve memory for emotional materials.

Although it is possible that acute exercise during consolidation acts as a stressor, which facilitates memory in a similar manner to stressors like the TSST or CPT, it is also possible that episodic memory improvements following exercise may be the result of general arousal processes. Exercise produces physiological arousal via sympathetic nervous system activation. An arousing material tends to be better remembered than a non-arousing material, and this effect has been linked to amygdala activity (for review, see Talmi, 2013). The amygdala also plays a role in memory consolidation, particularly for emotional materials (McGaugh, McIntyre, & Power, 2002), and so increasing amygdala activity during consolidation through exercise could promote memory performance.

The present study investigated the effects of acute resistance exercise performed during consolidation on memory for emotional images. Resistance exercise (i.e. strength training) builds muscle mass and improves muscle tone. As a physical stressor, the body responds to resistance exercise in the same way as it responds to other stressors (Cadore et al., 2009; Kokalas, Tsalis, Tsigilis, & Mougios, 2004; Mastorakos, Pavlatou, Diamanti-Kandarakis & Chrousos, 2005). Thus, it is plausible that even a single bout of resistance exercise might enhance episodic memory accuracy via similar mechanisms as other acute stressors.

We predicted that AA, heart rate (HR), and blood pressure (BP) would increase following exercise in the active group and be related to memory accuracy. Furthermore, we predicted an interaction between emotional content and exercise, such that the active group would exhibit better memory for emotional items only. Extensive behavioral evidence indicates that memory for negative information depends on recollection to a greater extent than does memory for neutral and positive information (Comblain, D'Argembeau, Van der Linden, & Aldenhoff, 2004; D'Argembeau & Van der Linden, 2005; Dolcos, LaBar, & Cabeza, 2004; Kensinger & Corkin, 2003). Because of this, we wanted to examine the independent contributions of recollection and familiarity. To this end, we used a remember–know recognition test to assess memory performance (Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998). Consequently, our final prediction was that recollection would be the highest for negative items, and greater in the active group compared to the passive group.

2. Method

2.1. Participants

Participants were randomly assigned to either the active or passive exercise conditions. There were 23 active participants (mean age = 20.61, 12 females) and 23 passive participants (mean age = 20.21, 17 females).[3] Active participants engaged in a resistance exercise task, and passive participants did not exercise. Participants received either $10 per hour and $5 per day for travel costs or course credit as compensation. Participants completed a health questionnaire to ensure that they did not have any medical conditions that could affect either their ability to complete the exercise task or the results of the study. Specifically, participants who had any of the following conditions were excluded from participating in this study: Parkinson's disease, Alzheimer's disease and other forms of dementia, multiple sclerosis, heart disease, untreated high/low blood pressure, a history of stoke or seizure, loss of consciousness, brain damage, heart attack, epilepsy, bipolar disorder, untreated depression or anxiety, Asperger's syndrome, attention deficit disorder, previous brain surgery, untreated cataracts, untreated glaucoma, macular degeneration, hearing difficulties, regular illegal drug use, obesity, left-handed individuals, sensory deficits in hands or legs, neurological disease, arthritis, cardiovascular disease, any fractures in the hand or leg within the past two years, or pregnant women. All participants signed consent forms approved by the Georgia Institute of Technology Institutional Review Board.

2.2. Materials

Stimuli for the episodic memory task consisted of 180 photographs from the International Affective Picture System (IAPS) and contained equal numbers of neutral, positive, and negative emotional images (Bradley & Lang, 2007). Appendix A contains a list of all of the IAPS images used for this study. The average valence and arousal ratings from the normed IAPS data are in Table 1. Negative images were more arousing that neutral [t (59) = 32.3, $p < 0.001$] and to a lesser extent positive images [t (59) = 2.34, $p = 0.02$]. Positive images were also more arousing than neutral images [t (59) = 29.9, $p < 0.001$]. The IAPS images consist of indoor and outdoor scenes containing people, objects, and animals. Negative images depict graphic and distressing

[3] We ran ANCOVAs with gender as a covariate, because of the gender differences in our groups. There were no main effects of gender or interactions with gender [all $Fs < 1$], so we concluded that gender was not a significant factor in our results.