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Muscle tension induced after learning enhances long-term narrative and visual memory in healthy older adults

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ABSTRACT

Arousing events are better remembered than mundane events. Indeed, manipulation of arousal, such as by muscle tension, can influence memory even when it occurs shortly after learning. Indeed, our founding study showed this approach can raise delayed memory performance in older adults to a level comparable to that of unaided young adults. Yet, systematic studies, especially those investigating different modalities or types of memory, have not been done. This study investigated the effects of a brief bout of isometric exercise via handgrip on narrative and visuospatial episodic memory in healthy elders. Forty-seven participants completed the Logical Memory subtest of the Wechsler Memory Scales III (LM) and the Benton Visual Retention Test (BVRT), followed alternately by no treatment and by moderately squeezing a sand-filled latex ball for 1-min (counterbalanced order and test forms). Isometric exercise significantly increased both positive and negative affect ratings. Retention was tested 2 weeks later. Delayed recall and recognition of LM was enhanced by arousal relative to control, as was recognition of the BVRT. The results extend past findings that muscle tension induced after learning modulates memory consolidation, extending findings in elders to suggest that a simple form of isometric exercise can have practical effects, such as aiding memory for stories and images.

1. Introduction

Information and events that are physiologically arousing, whether or not they evoke specific emotional reactions, are often better remembered than neutral or mundane information and events (McGaugh, 2000; Nielson & Jensen, 1994; Nielson & Meltzer, 2009). Typically, this enhancement of memory is apparent at longer (e.g., hours, days) vs. shorter retrieval delays (e.g., Costa-Miserachs, Portell-Cortés, Aldavert-Vera, Torras-García, & Morgado-Bernal, 1994; Revelle & Loftus, 1992; Torras-Garcia, Portell-Cortés, Costa-Miserachs, & Morgado-Bernal, 1997). Extensive research has associated this phenomenon with several specific biological consequences of arousal, including catecholamine stress hormones released by the adrenal glands that activate secondary signals in the brain (McGaugh, 2000; Nielson & Jensen, 1994) and with increased glucose release (Parent, Varnhagen, & Gold, 1999). Importantly, while heightened arousal typically occurs during the experience, and therefore during the encoding of information and events, empirical studies clearly demonstrate that moderate manipulation of arousal can also enhance memory when it occurs shortly after the event (Gold & van Buskirk, 1975; McGaugh, 1966; Nielson & Powless, 2007; Nielson, Radtke, & Jensen, 1996). As such, inherently arousing events are better remembered later, but so too are non-arousing memoranda and events that are followed soon in time by an unrelated but arousing stimulus (Nielson & Bryant, 2005; Nielson & Powless, 2007; Nielson, Yee, & Erickson, 2005; but see also Liu, Graham, & Zorawski, 2008). Additionally, emotion regulation strategies and a predisposition towards arousal can influence the effect of arousal on memory (Nielson & Lorber, 2009). Thus, in addition to informing research about the physiological and neural mechanisms underlying memory, this line of work suggests that the manipulation of arousal during or soon after learning might have potential as a tool in cognitive rehabilitation and memory intervention programs.

One particular technique, muscle tension, such as can be induced via handgrip, can induce arousal quickly and without specific affective quality or directionality (i.e., positive/negative). An acute bout of handgrip muscle tension increases breathing and heart rates, blood pressure (Kluess & Wood, 2005; Stewart, Montgomery, Glover, & Medow, 2006), and catecholamine levels, especially in older adults (Kremiński, Cybulski, Ziemba, & Nazar, 2012). "Optimal" handgrip tension (i.e., of moderate pressure) of at least 30 s has been associated with improved memory and processing speed (Bills, 1927; Courts, 1939; Stauffacher, 1937;

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Wood & Hokanson, 1965), and when induced after learning, it enhances memory for word lists (Nielson & Jensen, 1994; Nielson et al., 1996). Importantly, in the first study to investigate this approach with older adults, the amount of enhancement was enough to bring older adults' memory performance to the level of unmodulated younger adults, except in those who were taking 'beta-blockers' to treat hypertension, which interfere with the normal catecholaminergic response to arousal (Nielson & Jensen, 1994; Nielson et al., 1996). Despite its apparent utility, the effectiveness of handgrip tension to modulate memory has not been further investigated in recent years, with these or other types of memoranda nor in other memory systems.

Episodic memory is a primary focus of cognitive aging research because it consistently shows deterioration with advancing age (e.g., Haaland, Price, & Larue, 2003). Episodic memory has often been subdivided into more specific categories by the type of memoranda being learned. For example, visuospatial memory and visual memory are terms often used to describe episodic memory for pictures or graphical representations, while narrative memory is a term often used to describe verbal episodic memory for stories (cf. Rubin, 2006). Memory subsystems are affected differentially by the aging process (e.g., visual memory may deteriorate more rapidly than narrative or other verbal memory; Haaland et al., 2003; Jenkins, Myerson, Joerding, & Hale, 2000). Indeed, specifically examining different memory domains can clarify and enhance differential diagnoses in neurodegenerative diseases and advanced age (Chapman et al., 2010; Messinis, Lyros, Georgiou, & Papathanasopoulous, 2012; Zonderman et al., 1995). Specifically, separate cortical regions and pathways become activated when the type of stimuli being memorized varies (Ariza et al., 2006; Rolls, 2000) and age-related differences in memory may arise from a reliance on slightly different cognitive processes or strategies (Sharps, 1998).

Despite the importance of and diversity inherent in human memory, the literature on human post-event memory modulation has focused heavily on list-learning tasks. Indeed, visual and narrative episodic memory have not been examined in this context. Moreover, other types of episodic tasks such as visual and narrative memory may have greater ecological validity with older adults, given that memory for stories and pictures may be more commonly tested and desirable in their everyday lives than memory for word lists. Thus, the current study examined the effect of memory modulation on delayed narrative and visual memory. As arousal induced via moderate handgrip muscle tension has been previously documented to enhance delayed memory in older adults using other episodic memory tasks (Nielson & Jensen, 1994; Nielson et al., 1996), a similar method, was employed herein. Importantly, we sought to extend the literature while also simplifying the approach to an inexpensive one that could eventually be used outside the laboratory. Such an approach would be needed if this type of modulation could ever be employed as a memory intervention technique. As such, we used a non-mechanical, sand-filled "squeeze ball" (*Isoflex*©, Gayla Industries) to induce arousal via handgrip muscle tension. We hypothesized that both delayed narrative and visual memory would be enhanced by moderate arousal induced after learning relative to a control condition.

2. Method

2.1. Participants

A total of 59 healthy, older adults were recruited from existing subject lists. A multi-dimensional definition of healthy aging was employed (see Peel, Bartlett, & McClure, 2004) in which all participants lived independently, had an estimated IQ that was in the average range or higher, and were at least 60 years of age. Participants were excluded if they had formal education below grade 7, a diagnosis of dementia or other cognitive impairment, uncontrolled hypertension, or other unmanaged medical conditions that could affect either cognitive performance or the response to the experimental manipulation (e.g., neurological conditions, psychiatric Axis I conditions, Parkinson's disease, COPD, diabetes, etc.). While 52 of 59 recruits attended and completed the first session and attended the second session, 3 men and 2 women did not have complete or reliable second session data. Thus, 47 subjects are included in the final analyses (see Table 1). For this within-subject design study, participants were quasi-randomly assigned to arousal order groups, i.e., either Group A (arousal then neutral) or Group B (neutral then arousal).

2.2. Materials

2.2.1. General cognitive measures

To assure intact cognitive functioning and to allow evaluation of the comparability of order groups, participants were given broad cognitive tests. The Mini-Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975) is a screening measure for dementia. It briefly assesses orientation, attention, language, memory, visuospatial ability, etc. It is scored from 0 to 30, where scores of 26 or better generally indicating normal functioning in this age group. The Shipley Institute of Living Scale (Shipley; Zachary, 1986) is a 60-item instrument that measures vocabulary and abstract thinking, thereby allowing an estimate of verbal intelligence quotient (IQ).

2.2.2. Arousal induction

Muscle tension was induced by asking participants to squeeze a sand-filled latex ball (IsoFlex© Gayla Industries). Participants were instructed on how to use the arousal device prior to the experimental task. Each participant established a baseline by exerting maximum tension for 30 s using his/her preferred hand. Subsequently, during the experimental protocol, participants were asked at various times to squeeze a moderate amount (i.e., 25–50% of his/her baseline pressure) for 1 min; in other words, to squeeze the device "comfortably hard" (Courts, 1939; Nielson & Jensen, 1994; Nielson et al., 1996; Wood & Hokanson, 1965). This procedure typically produces a small (10-beat/minute) change in heart rate (Lynch, Schuri, & D'Anna, 1976; Nielson et al., 1996), far less exertion than typically used in studies examining exercise effects on cognition (Chang, Labban, Gapin, & Etnier, 2012; Lambourne & Tomporowski, 2010; Tomporowski, 2003). Yet, such exertion produces physiological effects similar to other arousing treatments, such as epinephrine administration, including an inverted-U dose response curve (e.g., Wood & Hokanson, 1965), that modulate memory processes (e.g., Cahill, Prins, Weber, & McGaugh, 1994; Clayton & Williams, 2000; Kerfoot, Chattillion, & Williams, 2008; Miyashita & Williams, 2006; Nielson & Jensen, 1994).

2.2.3. Memory tasks

The Logical Memory subtest of the Wechsler Memory Scale III (LM; Wechsler, 1997) is a test of auditory narrative memory (a subtype of episodic memory) with two comparable forms. Participants were presented with a short narrative, comprised of 15 significant elements, and needed to recall the story immediately after hearing it using as many of the exact words used in the original passage as possible. Story order was counterbalanced across subjects. A delayed recall test was also administered, 2 weeks later. Performance evaluation consisted of counting the number of principal events correctly recalled. A second score, evaluating 'thematic recall', which reflects more general level recall (i.e., 'gist') was also computed according to test instructions. A delayed recognition