Effects of the Stress of Marathon Running on Implicit and Explicit Memory

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Abstract

We tested the idea that real world situations, such as the highly strenuous exercise involved in marathon running, that impose extreme physical demands on an individual may result in neurohormonal changes that alter the functioning of memory. Marathon runners were given implicit and explicit memory tasks before, or immediately after, they completed a marathon. Runners tested immediately upon completing the marathon showed impairment in the explicit memory task, but enhancement in the implicit memory task. The impairment in the explicit memory task, post marathon, is similar to that seen with amnesic patients with organic brain damage. However, no previous studies have shown a simultaneous enhancement in the implicit memory task, as shown by the marathon runners in this study. This study indicates that human memory functioning can be dynamically altered by activities, such as marathon running, in which hundreds of thousands of healthy normal individuals routinely partake.

With the increasing understanding of the selective effects of neuromodulators, including stress hormones, that vary with the vicissitudes of daily living, comes the need to investigate human memory under the kinds of naturalistic conditions that may give rise to changes in the balance of these neuromodulators. Patterns of memory responses exhibited in the laboratory may or may not generalize to real world situations in which neuromodulator levels are altered. Memory dissociations have often been found with patient populations with focal brain damage. But such lesions are not the only situation, or even the most common, in which different memory systems or processes may be selectively engaged. The possibility exists that the differences in neuromodulators that obtain under real world conditions could produce memory dissociations in normal individuals similar to those seen in patient populations, dissociations that may be crucial for understanding the dynamics of human memory in the wild.

Exercise is an interesting (and pervasive) example of a behavior that has an influence on neuromodulators affecting memory. The emotional, cognitive, and physiological effects of moderate levels of aerobic exercise--which we would not consider stressful-- have been well documented. These include beneficial effects on mood (Byrne & Byrne, 1993), cognitive speed, auditory and visual attention (Angevaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008), and neurogenesis in the dentate gyrus of the hippocampus, a brain structure implicated in memory (Pereira, Huddleston, Brickman, Sosunov, Han, et al., 2007).

But what about the effects of heavy, strenuous exercise? Research into the physiological effects of marathon running-- the event which will be our focus here--

suggests the possibility of maladaptive consequences. Dehydration, gastrointestinal bleeding, muscle damage, immune suppression, and even sudden cardiac death have all been reported (see Uchakin, Gotovtseva, & Stray-Gundersen, 2003). Marathon running also greatly increases cortisol and norepinephrine --hormones that are elevated by physiological and emotional stress. Marathon runners' cortisol levels have been documented (Cook, Ng, Read, Harris, & Riad-Fahmy, 1987) to rise 4 fold above the highest levels induced by the most common laboratory-based stress task, the Trier Social Stress Task (Kirschbaum, Pirke, & Hellhammer, 1993). Indeed, cortisol levels recorded 30 minutes after completion of a marathon rival the levels reported in military training and interrogation (Taylor, Sausen, Potterat, Mujica-Parodi, et al, 2007), rape victims being treated acutely (Resnick, Yehuda, Pitman & Foy, 1995), severe burn injury patients (Norbury, Herndo, Branski, Chinkes, & Jeschke, 2008), and first time parachute jumpers (Aloe, Bracci-Laudiero, Alleva, Lambiase, et al., 1994). Other neurotransmitters, such as norepinephrine, are similarly elevated in marathon running (Demers, Harrison, Halbert, & Santen, 1981). Leading experts (Sapolsky, 2004, pp. 104) have concluded that marathon running is one of the most stressful activities in which normal, neurologically intact humans engage. The affective valence of marathon running is, of course, quite different from that of the traumatic situations referenced above. However, the physiological response is on a par with these events. No studies to date have examined the effects of marathon running on memory function, despite the opportunity that marathon running allows to ethically study the memorial impact of extremely high levels of stress hormones.

Here, we addressed the effects of marathon running on implicit and explicit memory tasks. We chose these tasks because they have previously been shown to dissociate with certain brain-damaged patients (see Graf & Schacter, 1985). Patients who have sustained hippocampal damage show impairments in what Graf and Schacter called 'explicit memories,' or memories elicited by questions such as 'tell me what happened an hour ago', or 'what were the items on the list you just read?' If shown a list of words and told to remember them, they may be unable to recall any of them. Despite this deficit, these patients show intact implicit memory. They exhibit performance as good as that of non-amnesics for the words on the list in an implicit memory task where a few letters of the words are given and the patient is asked to complete the words.

Previous research has linked elevated cortisol levels to deficits in explicit memory. In these studies, high doses of cortisol alone have been administered, either orally or intravenously, in the form of methylprednisolone, a synthetic glucocorticoid. The results showed decreases in verbal declarative memory and word recall (e.g., de Quervain, Roozendaal, Nitsch, McGaugh, & Hock, 2003; Newcomer, Selke, Melson, Hershey, Craft, Richards et al., 1999). One explanation for these findings is that cortisol's affinity within the hippocampus for binding to glucocorticoid receptors may have resulted in a reversible hippocampal dysfunction (de Kloet, Vreugdenhil, Oitzl, & Joels, 1998). Thus, the cortisol studies and amnesia studies may be related, with memory deficits in both being attributable to hippocampal impairment--permanent in one case; reversible in the other. Based on these results, we hypothesized that marathon runners immediately after the race, when cortisol levels are at their highest levels, but not several days before the race, when cortisol levels are close to normal, would show deficits in an explicit memory task. Marathon running, however, results in many changes other than increased cortisol levels, and a variety of these factors could contribute to impairments in explicit memory.

What should happen to other kinds of memory is less clear. Demers et al. (1981), reported that epinephrine and norephinphrine are greatly increased during and after a marathon. Increases in such neurotransmitters have been shown to result in enhancements in emotional responses, fear, and appetitive conditioning (Cahill & Alkire, 2003; LeDoux, 1996, McGaugh, 2004). Given that stress hormones, other than cortisol, that might enhance memory performance are augmented by marathon running, it seemed possible that performance on an implicit memory task might either be spared, as with amnesics, or indeed might even be enhanced. Evolutionarily it seems plausible that a stressor might not only have inhibiting effects, but rather, it might serve also to selectively enhance certain functions.

We used the same implicit word-stem completion and explicit cued recall tasks and instructions used by Graf and Schacter (1985) that showed the classic dissociation of memory function in amnesics. Our hypothesis was that when marathon runners had just undergone the stress of running a marathon as compared to several days earlier, their performance on the explicit cued recall task would be impaired. At the same time, we predicted that their performance on the implicit stem-completion task would either be spared, or might even be enhanced.

Method

Participants. The 261 participants included in the sample were between the ages of 18 and 65 and were verified by bib number to have completed either the New York City or the Boston marathon during the week we tested them. Twenty-two additional people who were tested were excluded without being scored because they were observed by the experimenter to have cheated, or because their native language was not English. The Control condition participants were 120 marathon runners, 55 men and 65 women, mean age = 36.56 years, recruited and tested at an event 1-3 days before the marathon that they ran. Some participants (68) were tested between the hours of noon and 5pm, while others (52) were tested between 6pm and 9pm. Using Control group individuals who were marathon runners, confirmed to have completed the race, helped to ensure that observed differences in memory were related to the effects of having just run the race, rather than to personality, fitness, socio-economic status, or the myriad of other factors that might differentiate people who run marathons from people who do not. We could not rigorously control all possible factors. For example, although it was our subjective impression that the overwhelming majority of people in both groups agreed to participate, a few people did decline. The reasons given were that they were meeting friends, going to eat, and, in the marathon group, a few declined because they were tired. There were few such people, however, in either group. Participants in the Marathon group (n = 141, 86 men and 55 women, mean age = 36.21 years) were recruited and tested approximately 30 minutes after completing the marathon at the race's designated reception area between the hours of noon and 5pm.

All participants, who were unpaid volunteers, gave informed consent before they began the study, conforming to APA guidelines, and approved by the Columbia University IRB. Participants also gave permission to have their times verified.

The amount of noise and celebration was approximately the same at the pre-race convention areas and the post-race meeting areas where we tested. It was decided not to recruit participants at the Los Angeles marathon, for example, because loud music –which could pose an external distraction-- was played at the finish of that race. Neither the NYC nor the Boston marathon has this problem.

Materials. The materials consisted of 39 words and their 3-letter word stems, chosen from Graf and Williams' (1987) normed word pool. Words consisted of nouns, verbs, and adjectives, and had an average length of 5.6 letters (range: 4-7 letters). The materials were individually randomized for each participant: each item was randomly assigned to be either a studied item tested in the explicit condition, a studied item tested in the implicit condition, or an unstudied item tested in the baseline implicit condition. The computer randomly ordered words from the base set of 39 into each condition and printed individual booklets for each participant. Data were hand scored using individual scoring keys that were generated by the computer for each participant. A grid number allowed the scoring keys to be collated with the test booklets.

Procedure. After being consented, participants were given the paper booklet containing the study materials. On the first page was the study event. Participants made pleasantness ratings for 26 words, chosen at random from the pool of 39 total words, on a 5-point scale. On the following page, participants were told that each of the cues on the next page would be the beginning of an English word. Their task was to write a few letters to make each cue into a word. They were instructed that they could write any English word, but that they were to write down the first one that came to mind. The next page–the implicit word-stem completion task-- contained word stems from 13 words that were previously rated for pleasantness, as well as stems from 13 unrated (baseline) words, randomly intermixed. Following completion of the implicit memory task, they were given instructions for the explicit memory cued recall task. They were told that each of the cues on the next page was the beginning of a word for which they had provided a pleasantness rating earlier. They were instructed to try to complete each cue with the word from the pleasantness-rating list; that is, to explicitly remember the previously rated words. They were also instructed not to look back at the list. Once they had read these instructions, they turned to the last page, which contained the remaining 13 three letter word-stems presented in a random order, all of which had previously been rated for pleasantness. They then attempted to recall the words given the cues. Instructions for both tasks were modeled after the ones developed by Graf and Schacter (1985) to test the implicit and explicit memory in amnesic patients. The study was self-paced, and took participants on average 10 minutes to complete the entire booklet. The time between study and both memory tasks was marginal.

The order of the tasks was fixed. The implicit task always preceded the explicit task. This fixed task order has been implemented in the majority of previously published experiments in which these memory measures are manipulated as within-subject factors (see Backman, Almkvist, Andersson, Nordberg, Winblad et al, 1997; Graf & Mandler, 1984; Graf & Schacter, 1985). Indeed, in one of the few studies published where the order of tasks was counterbalanced, problematic order effects affecting the implicit task were reported when the explicit test came first (Kihlstrom, Schacter, Cork, Hurt, & Behr, 1990). This is because once the individual has performed the explicit memory task, they are no longer naive to the idea that they are being tested for memory for the words that they made pleasantness ratings about. Until the explicit task is given, however, the chance that the participant knows that the words that they rated are related to the word-stem completion task is low. Maintaining a fixed order, with the implicit task preceding the explicit task, although not guaranteeing that an explicit strategy is not used in the implicit task, helps to ensure that the implicit task be implicit.

Results

As can be seen from Figure 1, the proportion of words correctly recalled from the previously studied list on the explicit memory (cued recall) task was lower for the Marathon group as compared to the Control group, as predicted. However, on the implicit memory (word-stem completion) task, the Marathon group preformed better than the Control group. The implicit memory score was a priming measure, computed as the difference in the proportion of correctly completed presented words minus the proportion of correctly completed unpresented (baseline) words (i.e., a correctly completed stem from our original list, despite the word not having been presented at encoding). A repeated-measures ANOVA revealed an interaction between Group (Marathon versus Control) and Memory Task (implicit versus explicit), $F(1, 259)=16.73$, $MSe = 5.69$, $p < .001$, $\eta_p^2 = .06$, (effect size is reported using partial eta squared, η_p^2). Post hoc tests confirmed that performance on the explicit memory task was worse for the Marathon group than for the Control group, $t(259) =2.05$, $p=.04$, and that performance was significantly better for the Marathon group, as compared to the Control group, on the implicit memory task, $t(259)= -3.38$, $p=.001$. Baseline implicit memory performance was the same for the Control (m= .06) and Marathon (m= .06) groups, *t*(259)=1.45, *p*=.15, *ns*.

Control group participants averaged slower running times than did Marathon group participants, *t*(259)=6.62, p<.001. We therefore performed two ANCOVAs, the first with Implicit score as the dependent variable, Group as the fixed factor, and Running Time as the covariate. There was no effect of Running Time on implicit memory (B=-.12 scale units/hour, SE=.24, *t*(259)=-.63, p=.53, *ns*). When controlled for time, the Group effect was still significant, *F*(1, 258)=8.32, *MSe* =6.27, p=.004. We performed the analogous ANCOVA with the Explicit scores. Running Time, here, had a significant effect (B=-.66 scale units/hour, SE=.24, *t*(259)=-2.68, p=.008). The effect of Group, controlled for Running Time, *F*(1, 258)=8.62, *MSe* =6.65, p=.004, was slightly stronger than before, indicating that the difference in running times across Groups had been partially masking the negative effects of marathon running on the explicit memory task.

Additional analysis. The interaction persisted when we analyzed the Boston participants alone *(F*(1, 110)=4.53, *MSe*=5.82, *p*=.035, η_p^2= .04), and the New York participants alone (*F*(1, 147)=6.28, *MSe* =5.39, *p*=.01, η_p^2= .04). The interaction, remained significant for men alone (*F*(1, 139)=6.27, *MSe* =5.51, *p*=.014, η_p^2= .04), and for women alone (*F*(1,118)=8.63, *MSe* =5.91, *p*=.004, η_p^2= .07). Although there was no difference in age between the two groups, we nevertheless ran two separate ANCOVAS, with Group as the fixed factor and Age as the covariate. With neither Implicit nor Explicit performance was there a Group effect of Age (Implicit: B=0.02 scale units/year, SE=0.02, T=1.03, p=.31, *ns*, *F*(1, 258)=11.57, *MSe* =6.26, p=.001; Explicit: B=-0.007 scale units/year, SE=0.19, T=-0.35, p=.73, *ns*, *F*(1, 258)=4.21, *MSe* =6.83, p=.04). Finally, 52 Control participants were recruited at a race-related party that took place after

5pm. We therefore did a subsequent analysis eliminating these participants, and using only Control and Marathon Group participants who were controlled for time of day. As before, the interaction between Group (Marathon versus Control) and Memory Task (implicit versus explicit) was significant, $F(1,207)=20.24$, $MSe = 5.64$, $p < .001$, $\eta_p^2 = .09$.

Discussion

These data revealed a double dissociation of the effects of marathon running on an implicit and an explicit memory task. We interpret the results to suggest that complex neuromodulation associated with extreme stress enhances some brain systems while, at the same time, inhibits others. Other possible explanations for these results, however, could be raised.[i] As acknowledged in our introduction, marathon running results in a host of other physiological changes, and various of these factors could have led to decrements in explicit memory. However, consideration of those factors alone provides no obvious explanation of why marathon running led to improved implicit memory.

Healey, Campbell, and Hasher (2008) have reviewed task tradeoffs that, on the face of it, seem similar to the one shown here. Older adults, in their studies, showed impaired memory for material to which they were supposed to attend to, while at the same time showed enhanced memory for surrounding items, which were supposed to have been ignored. The authors suggested that one effect of aging might be that people are less focused on the target task and may attend to information that is non-focal to the nominal task at hand. Priming of, and thus enhanced performance on, non-focal material may ensue. This explanation holds up well for why older adults sometimes show memory enhancement, as compared to the performance of younger participants, depending on the task at hand. However, in contrast to the results described with the older adults, in which attention was paid to items that were non-focal at encoding, in our experiment, all of the materials--both those used in the implicit task and those in the explicit task--were focal at encoding. Participants made pleasantness judgments about all of the words--those that would later appear in the implicit condition as well as those later to be tested explicitly. Given that the words that would appear in the implicit task and those that would appear in the explicit task were indistinguishable at encoding, a 'dispersed attention' explanation does not seem able to explain the present results.

A simpler view of the effects of this kind of stress might be that it was just simply distracting (Schmitter-Edgecombe, 1996). A distraction explanation might be able to account for a finding of impaired performance on the explicit task. However, it cannot simultaneously account for enhanced performance on the implicit memory task. Simple distraction should hurt, not enhance, performance. We are left with the conclusion that stress enhanced some functions while harming others.

These data contribute to our understanding of how stress mediates human memory. Interestingly, performance on the implicit memory task was enhanced rather than unaffected or impaired. Amnesics typically show the same implicit memory performance as controls; they have not, in any study published to date, shown implicit memory performance that was significantly better than that of control participants. However, there are some salient differences between amnesics and marathon runners. The latter do not have organic brain damage, for one thing. For another, it is highly unlikely that the effect of the stress hormones accompanying extreme exercise affect only one structure such as the hippocampus (as is sometimes the case with amnesics). Stress hormones, including norepinephrine, endorphins, and others are surging in the marathon runners. It is not unreasonable to suppose that these serve to improve certain kinds of mental function. Thus, either because the implicit and explicit systems have an inherently reciprocal relation in normals, or, perhaps because the different neuromodulators associated with extreme exercise have opposing effects on different subsystems--improving one while impairing another--the manipulation in our experiment revealed a double dissociation.

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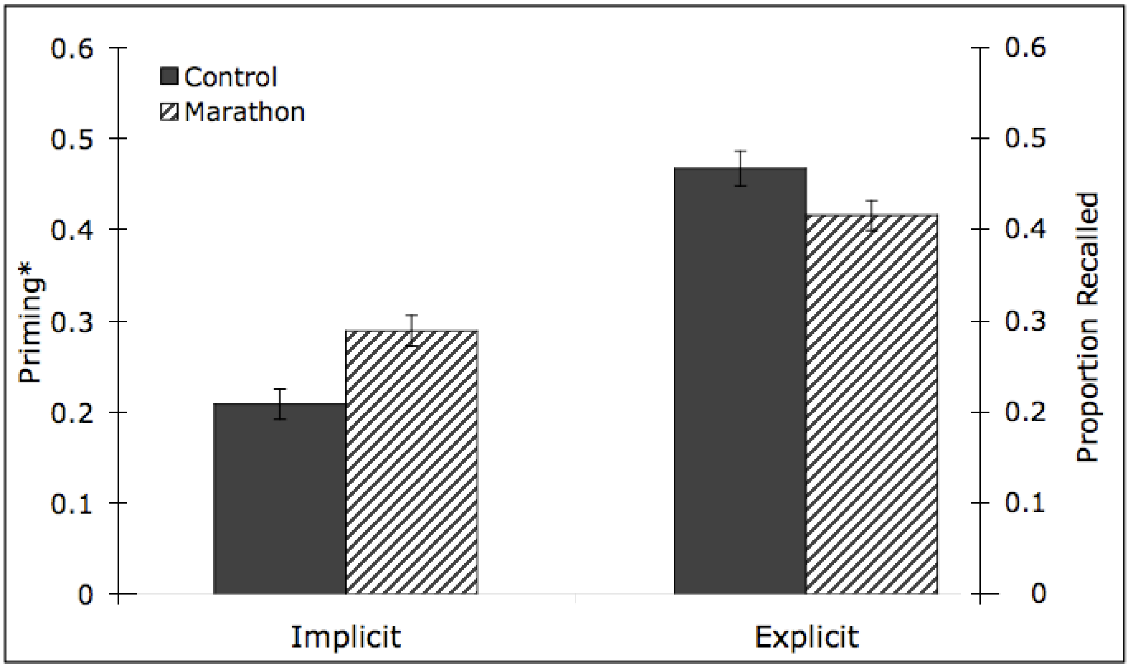
Figure Caption

Figure 1. Performance on the Implicit and Explicit Memory Tasks. The left bars give the difference between the Control (pre-marathon) and Marathon (post-marathon) Groups on the implicit memory word-stem completion task. The right bars give Control group and Marathon group performance on the explicit cued recall task. *Priming is the difference in the proportion of correctly completed presented words minus the proportion of correctly completed unpresented (baseline) words.

Figure 1.


0.6
0.5
0.4
0.3
0.2
0.1
0
Priming*
■ Control
▨ Marathon
Proportion Recalled
Implicit
Explicit

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[i] An anonymous reviewer suggested that the Yerkes-Dodson law might be applicable to these results.