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Original Research

Experimental Effects of Acute Exercise in Attenuating Concurrent Memory Interference

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Abstract

Acute exercise may enhance episodic memory recall, or the retrospective recall of an event or episode due to exercise-induced neuronal excitability and ensuing long-term potentiation. Of interest to this paper is the potential effects of acute exercise on memory interference, when the interfering stimuli occurs at the same time as the target stimuli. A three-arm, parallel-group randomized controlled intervention was employed. Participants (N=50) were randomized into one of three groups, including 1) Interference + Exercise, 2) Interference Only, and 3) Control (no interference and no exercise). The Interference component refers to the concurrent memory interference stimuli. The experimental conditions, although different for each group, included exercising at 70% of heart rate max, completing an online Sudoku puzzle during rest periods, completing a computerized Stroop task (word-color), listening to a pre-recorded 15-word list, and subsequently recalling the words after observing a 20-minute video clip. For the memory assessment, the Control condition (i.e., no interference and no exercise) had significantly higher immediate memory (7.76 words) when compared to the interference +

Exercise (P=0.0003; 4.70 words) and Interference (P<0.0001; 3.93 words) groups. For delayed memory recall, the Control group recalled more words than the Interference + Exercise (P=0.001) and Interference groups (P=0.0003), but there was no statistically significant difference between Interference + Exercise and Interference only (P=0.24). These results provide strong evidence for a concurrent memory interference effect. We did not, however, demonstrate statistical evidence that acute moderate-intensity exercise attenuates a concurrent memory interference effect.

Keywords
Memory; proactive interference; retroactive interference; concurrent memory interference; prefrontal cortex; Stroop Task

1. Introduction

Recent work from our laboratory demonstrates that acute exercise may enhance episodic memory recall [1-5], or the retrospective recall of an event or episode [6]. We have detailed the mechanisms of this effect elsewhere [7-9], which includes, for example, exercise-induced neuronal excitability and ensuing long-term potentiation [10]. Of interest to this paper, written as a brief report, is the potential effects of acute exercise on memory interference. Typically, memory interference is subdivided into either proactive or retroactive memory interference. Proactive memory interference occurs when a previously learned memory interferes with the learning process of a subsequent memory stimulus. Conversely, retroactive interference occurs when newly acquired information interferes with previously acquired information.

It is conceivable that acute moderate-intensity exercise may help to minimize a memory interference effect. Memory interference appears to be influenced by the medial prefrontal cortex, as this structure may attenuate a memory interference effect via encoding (facilitating pattern separation) and retrieval (facilitating inactivation of the interfering engram) mechanisms [11]. To our knowledge, only three published experiments have evaluated the effects of acute exercise on attenuating cognitive-related memory interference [12-14], as opposed to motor-related memory interference [15, 16]. These experiments come from our laboratory and demonstrate some, albeit limited, evidence that exercise may help to attenuate a memory interference effect. We speculate that this potential effect comes from exercise-induced alterations in prefrontal cortex function [11, 17-19].

Adding additional novelty to this line of inquiry, the present experiment evaluates whether acute moderate-intensity exercise can attenuate a concurrent interference effect, which has yet to be investigated. That is, herein we examined whether acute exercise can attenuate an interference effect when the interfering stimuli occurs at the same time as the target stimuli. This contrasts with proactive (interfering stimuli occurs before target stimuli) and retroactive interference (interfering stimuli comes after the target stimuli). We hypothesize that acute exercise will attenuate a concurrent memory interference effect. Such an effect is plausible, as, in theory, working memory capacity may play a critical role in attenuating concurrent memory interference, and acute exercise has been shown to enhance working memory capacity [20].

2. Methods

2.1 Study Design

A three-arm, parallel-group randomized controlled intervention was employed. This study was approved by the authors' institutional review board. All participants provided written consent prior to participation.

Participants were randomized into one of three groups, including 1) Interference + Exercise, 2) Interference Only, and 3) Control (no interference and no exercise). The interference component refers to the concurrent memory interference stimuli. Further details are described below.

2.2 Participants

In total, 50 participants were recruited, including 17, 16, and 17 in the Interference + Exercise, Interference Only, and Control groups, respectively. Recruitment occurred via a convenience-based, non-probability sampling approach (classroom announcement and word-of-mouth). Participants included undergraduate and graduate students between the ages of 18 and 35 yrs.

Additionally, participants were excluded if they:

- Self-reported as a daily smoker [21, 22]
- Self-reported being pregnant [23]
- Exercised within 5 hours of testing [24]
- Consumed caffeine within 3 hours of testing [25]
- Had a concussion or head trauma within the past 30 days [26]
- Took marijuana or other illegal drugs within the past 30 days [27]
- Were considered a daily alcohol user (>30 drinks/month for women; >60 drinks/month for men) [28]

2.3 Experiment Protocols

A schematic of the experimental protocol is shown in Figure 1 and detailed hereafter.

Interference + Exercise. Participants exercised for 15-minutes on a treadmill (details described below). Afterward, they rested (seated) for 5-minutes while playing Sudoku (details described below). After this 5-minute rest period, we employed a cognitive paradigm that resembles the dual-task paradigm. Participants completed a computerized Stroop task (word-color). This task took approximately 3-minutes to complete. They first completed this entire task as a familiarization trial. After completing the familiarization trial, they re-completed the task. At the 30-second point into this task, they listened to a pre-recorded list of 15-words (1.5 seconds per word) via headphones. After a 10-second delay, the re-listened to the list a second time and then immediately performed a free-recall (short-term memory). Following this, they finished completing the Stroop task. Afterward, they watch a video clip ("The Office – Bloopers") for 20-minutes (as a distractor) and then were asked to recall as many words as possible from the word list.

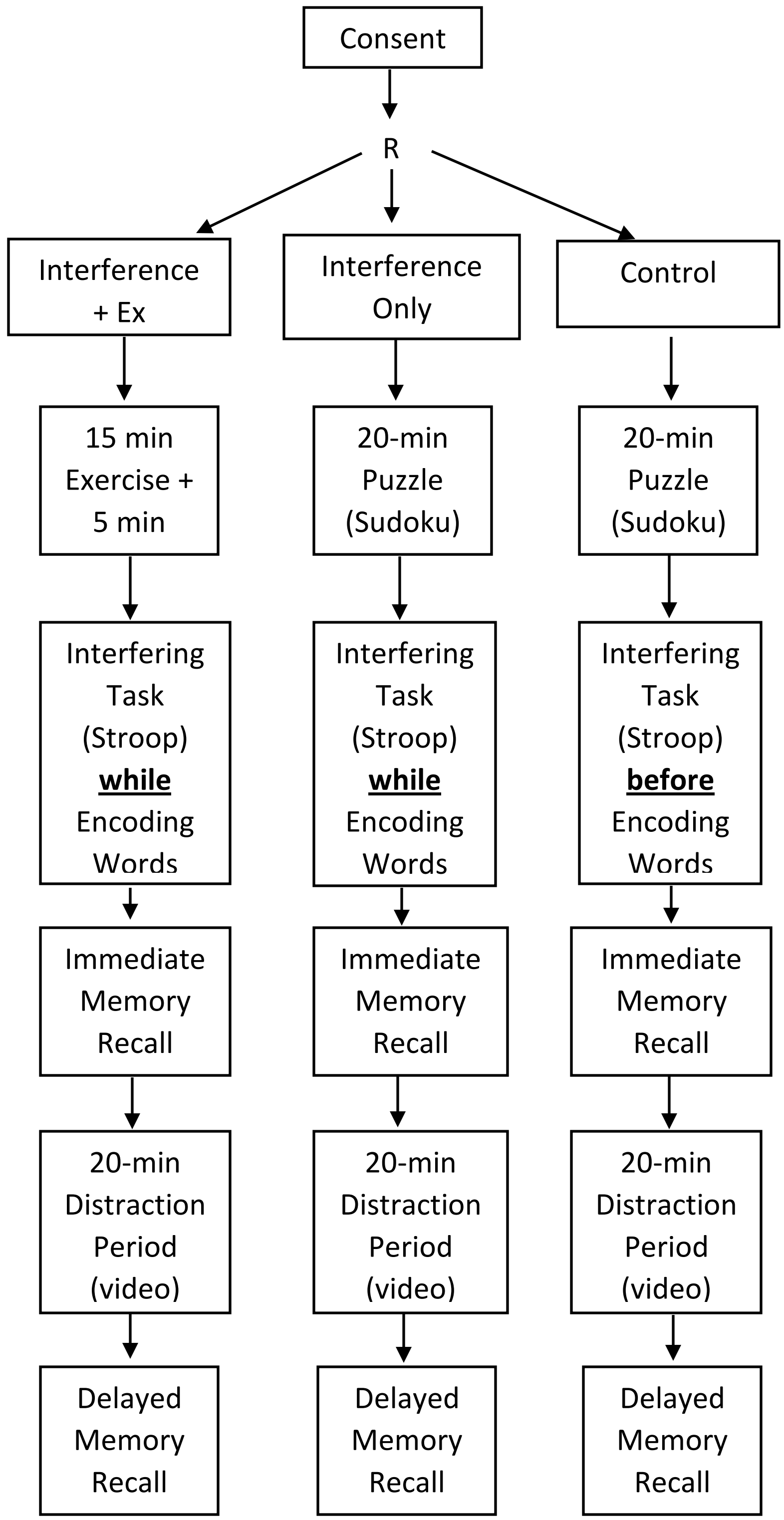

Figure 1 Schematic of the study protocol.

R = Randomization; Ex = Exercise

> Notably, at the beginning of the task, they were instructed as follows: "*You are now going to complete a practice trial of the Stroop task. It should take approximately 3-minutes. After you complete this practice trial*, *you will re-complete this task. While completing this task the second time, you will hear a recording of 15-words through the headphones. This recording will play twice. Please do your best to try and remember as many of these words as possible, as later in the experiment you will be asked to recall these words. It is also important that you do your best on the Stroop task. Thus, try and focus on both tasks (Stroop and listening to the words) at the same time. Both tasks are of equal importance as we will be evaluating your scores on both tasks."*

Interference Only. This group completed the same protocol as the Interference + Exercise Group, with the exception that they did not exercise. Instead of exercising for 15-minutes followed by a 5-minute rest period (above group), they played Sudoku for 20-minutes before starting the Stroop task.

No Interference and No Exercise (control). This group played Sudoku for 20-minutes. Then they completed two rounds of the Stroop task (results from the second Stroop task were recorded). After completing the second Stroop task, they listened to the word list twice (10-sec break). After listening to the word lists, they performed an immediate free-recall and then watched a video clip ("The Office – Bloopers") for 20-minutes. Following this, they were asked to recall as many words as possible from the word list.

2.4 Exercise Protocol

Participants randomized to the exercise group exercised (brisk walk) on a treadmill for 15 minutes. Participants exercised at approximately 70% of their estimated HR max (220-age), which constitutes moderate-intensity exercise [29]. The target heart rate was calculated prior to the exercise bout and the treadmill incline and speed were altered at the very beginning of the exercise to ensure heart rate approached the target level within the first few minutes of exercise.

Immediately after the bout of exercise, participants rested in a seated position for 5 minutes. Similar to other studies [30], during this resting period, they played on-line game of Sudoku (described below) to prevent boredom. After this resting period, they commenced the memory assessment, as described below.

2.5 Control Protocol

The Sudoku task involved a medium-level, on-line administered, Sudoku puzzle. The website for this puzzle is located here: https://www.websudoku.com/

2.6 Memory Assessment

Word List Task. 15 words were extracted from the Toronto Word Pool, all with imagery scores > 5. Participants listened to these words, delivered at a rate of 1 word per 1.5 seconds, via headphones. Previous research demonstrates evidence of test-retest reliability for related word-list memory tasks [31].

Stroop Task. The Stroop color word test is a well-documented prefrontal activation task indicative of executive function [32], which demonstrates adequate psychometric properties [33]. Testing of the Stroop effect was performed using computerized software. Specifically, the color word Stroop testing with keyboard responding was used. Participants were given color words (e.g. "red") written in color and asked to indicate the color of the word (not its meaning) by specific key presses. They were instructed to accomplish this as quickly and accurately as possible. There were 84 total trials, consisting of 4 colors (red, green, blue, black) x 3 color-stem congruency (congruent, incongruent, control) x 7 repetitions. The stimuli remained on the screen until the key response, with latencies measured from the onset of the stimuli. The congruent trials involved the color word and the color it presented being the same; incongruent trials involved the color word being different than the color it was presented in (e.g., it read GREEN, but this word was not in the green color); and the control trials involved colored rectangles. The outcome measure was the average latency (in milliseconds [ms]) of the correctly identified congruent, incongruent and control trials.

2.7 Additional Assessments

Various demographic (e.g., BMI), behavioral (e.g., habitual physical activity and resistance exercise) and psychological (e.g., RPE) assessments were completed to ensure that the groups were similar on these parameters. As a measure of habitual physical activity behavior, participants completed the Physical Activity Vital Signs Questionnaire to evaluate time spent per week in moderate-to-vigorous physical activity (MVPA) [34]. Height/weight (BMI; kg/m^2) were measured to provide anthropometric characteristics of the sample. Lastly, before and after the exercise and control conditions, heart rate (chest-strapped Polar monitor, F1 model) was assessed.

2.8 Statistical Analysis

All statistical analyses were computed in Stata (v. 12). A one-way ANOVA was used to compare the Stroop scores across the three groups, with Bonferroni-corrected post-hoc tests employed. A one-way repeated measures ANOVA was employed for the word-list task. Main effects for time and group, as well as group by time interaction effects, were evaluated. Statistical significance was set at an alpha of 0.05. Partial eta-square (η^2_p) was calculated as an estimate of effect size.

3. Results

Table 1 displays the demographic characteristics of the analyzed sample. The mean (SD) age of the entire sample was 21.3 (1.6) yrs, with the sample being predominately female (60%). There were no statistically significant differences for the demographic or behavioral characteristics across the 3 conditions; however, gender approached statistical significance (P=0.05).

Table 1 Characteristics of the sample.

Variable	Interference + Exercise	Interference Only	Control	P-Value
N	17	16	17	
Age, mean years	21.1 (1.6)	21.8 (2.1)	21.1 (1.1)	0.36
Gender, % Female	41.2	56.3	82.4	0.05
Race, % non-Hispanic white	94.1	62.5	76.5	0.23
BMI, mean kg/m^2	24.5 (3.1)	26.8 (6.4)	24.1 (3.3)	0.19
MVPA, mean min/week	224.1 (172.9)	185.6 (131.2)	160.3 (68.4)	0.37

BMI, body mass index

MVPA, moderate-to-vigorous physical activity

Values in parentheses are standard deviations

An ANOVA was used to calculate the P-values for the continuous variables (e.g., age), whereas a chi-square analysis was used for the categorical variables (e.g., gender).

Table 2 displays the physiological (heart rate) responses to the exercise and control conditions. There was a statistically significant time by group interaction (F=111.3, P<0.001, η^2_p=0.83). That is, non-exercise conditions (Interference Only and Control) had steady heart rates over the 20-minute period (prior to cognitive assessment), while the exercise condition increased their heart rate from 76.7 (9.2) to 130.4 (14.1) bpm.

Table 2 Heart rate responses across the three conditions.

Variable	Interference + Exercise	Interference Only	Control	Test-Statistic
N	17	16	17	
Baseline heart rate, mean bpm	76.7 (9.2)	73.3 (12.7)	70.1 (14.5)	F(time)=69.9, P<.001, η^2_p=0.60 F(group)=61.4, P<.001, η^2_p=0.73 F(time x group)=111.3, P<.001, η^2_p=0.83
Endpoint heart rate, mean bpm	130.4 (14.1)	68.2 (10.8)	67.4 (9.4)	

Values in parentheses are standard deviations.

Table 3 displays the cognitive scores across the experimental conditions. There was a significant main effect for Stroop type (F=34.5, P<.004, η^2_p=0.45), a significant main effect for group (F=3.25, P=.04, η^2_p=0.13), and a significant Stroop by group interaction (F=2.67, P=.03, η^2_p=0.11). Across the three conditions, there was no difference for Stroop-congruent (F=1.13, P=0.33, η^2_p=0.05) or Stroop-control (F=2.84, P=0.07, η^2_p=0.12), but Stroop-incongruent was significant (F=4.70, P=0.01, η^2_p=0.18).

For Stroop-incongruent, Interference + Exercise was not different than Interference Only (P=0.85) but was worse than Control (P=0.002). Similarly, Interference Only had a higher (worse) Stroop-incongruent score than Control (P=0.01).

Table 3 Cognitive scores across the experimental conditions.

Variable	Interference + Exercise	Interference Only	Control	Test-Statistic
N	17	16	17	
Stroop, mean ms				
Congruent	890.0 (157.0)	928.0 (209.0)	837.0 (139.1)	F(Stroop)=34.5, P<.001, η^2_p=0.45 F(group)=3.25, P=.04, η^2_p=0.13 F(Stroop x group)=2.67, P=.03, η^2_p=0.11
Incongruent	1193.0 (276.0)	1172.0 (348.9)	929.0 (137.4)	
Control	948.9 (140.5)	955.2 (178.1)	830.7 (167.1)	
Memory, mean # of words				
Immediate Recall	4.70 (1.7)	3.93 (1.3)	7.76 (2.4)	F(time)=53.3, P<0.001, η^2_p=0.53 F(group)=16.7, P<0.001, η^2_p=0.41 F(time x group)=0.12, P=0.89, η^2_p=0.01
Delayed Recall	3.23 (1.4)	2.68 (1.1)	6.41 (3.4)	

Values in parentheses are standard deviations.

Mean memory scores are also displayed in Table 3, with individual immediate memory recall and delayed memory recall scores, respectively, shown in Figure 2 and Figure 3. For the memory assessment, there was a significant main effect for time (F=53.3, P<0.001, η^2_p=0.53), main effect for group (F=16.7, P<0.001, η^2_p=0.41), but no time by group interaction (F=0.12, P=0.89, η^2_p=0.01). The Control condition (i.e., no interference and no exercise) had significantly higher immediate memory (7.76 words) when compared to the Interference + Exercise (P=0.0003; 4.70 words) and Interference Only (P<0.0001; 3.93 words) groups. Although the Interference + Exercise (4.70 words) recalled more words than the Interference Only (3.93 words) group for the immediate recall, this was not statistically significant (P=0.18). Similar results occurred for delayed memory recall. That is, the Control group recalled more words than the Interference + Exercise (P=0.001) and Interference Only groups (P=0.0003), but there was no statistically significant difference between Interference + Exercise and Interference Only (P=0.24).

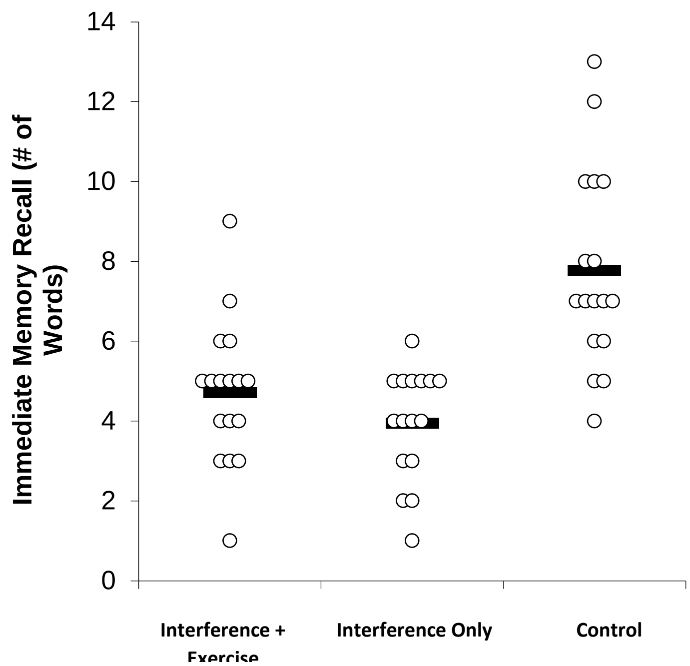

Figure 2 Immediate memory recall across the 3 conditions.

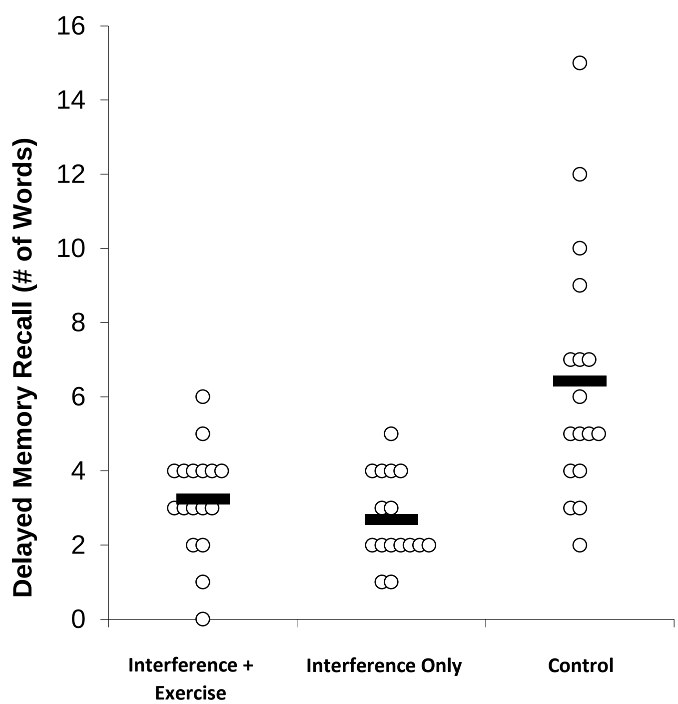

Figure 3 Delayed memory recall across the 3 conditions.

4. Discussion

Only three published experiments, to date, have examined the effects of acute exercise on either proactive and/or retroactive cognitive-related memory interference [12-14]. The present experiment extends this emerging line of inquiry by evaluating whether acute moderate-intensity exercise can attenuate a concurrent memory interference effect. The main findings from this experiment are as follows. We demonstrated evidence of a concurrent memory interference effect, as the control group (i.e., no concurrent interference) performed significantly better on the Stroop-incongruent task and on both the immediate and delayed episodic memory assessments. Regarding whether acute exercise could attenuate a concurrent memory interference effect, our results provided some evidence to suggest this may be possible. That is, the Interference + Exercise (4.70 words) group recalled more words than the Interference Only (3.93 words) for the immediate memory recall. Results were similar for the delayed memory recall assessment (3.23 vs. 2.68 words). However, these differences were not statistically significant.

As indicated in other work, acute moderate-intensity exercise may help to facilitate prefrontal cortex functioning. For example, Tsujii et al. [35] demonstrate that acute moderate-intensity exercise improved prefrontal cortex-dependent memory function and increased cerebral oxygenation in the prefrontal cortex. Other work demonstrates that acute moderate-intensity exercise increases neural activity in the prefrontal cortex [36]. One potential explanation for our null exercise interference findings is that, perhaps, our intensity level was too low [37]. Emerging work demonstrates that high-intensity acute exercise improves prefrontal cortex function [38]. Our recent empirical work [1] and review [39] provides support for high-intensity exercise on memory function. Further, animal work demonstrates that a single bout of high-intensity exercise can induce BDNF-TrkB signaling in the prefrontal cortex [40], which we have thoroughly discussed elsewhere as playing an important role in memory function [41]. Another potential explanation for our observed null findings may be from the absence of a sleep period (to facilitate memory consolidation) between memory encoding and recall [42]. Further, there was a greater proportion of females in our control group, which could have contributed to our null exercise interference findings. As we have demonstrated elsewhere [43], females tend to outperform males on verbal memory tasks; however, as we recently demonstrated [44], gender does not appear to moderate the effects of acute exercise on memory function.

Limitations of this study include the relatively small homogenous sample, which may limit our study's generalizability and statistical power. Thus, future work should consider expanding this line of inquiry to other, more diverse populations. Such work should also consider evaluating a bout of higher-intensity exercise, which may have a greater effect on attenuating concurrent memory interference.

In conclusion, this novel experimental study demonstrates that we were effective in inducing concurrent memory interference. We did not, however, demonstrate statistical evidence that acute moderate-intensity exercise attenuates a concurrent memory interference effect.

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Author Contributions

Author H.L. collected the data. Authors H.L. and L.C. provided feedback on the manuscript. Author P.L. supervised the project and drafted the manuscript.

Competing Interests

The authors have declared that no competing interests exist.

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