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Phosphatidylserine and caffeine attenuate postexercise mood disturbance and perception of fatigue in humans

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ABSTRACT

Phosphatidylserine (PS) may attenuate the adverse effects of physical fatigue. Therefore, we investigated the effects of a multi-ingredient supplement containing 400 mg/d PS and 100 mg/d caffeine (supplement [SUP]) for 2 weeks on measures of cognitive function (CF), reaction time (RT), and mood (MD) following an acute exercise stress. It is hypothesized that PS will maintain preexercise CF and RT scores, while attenuating postexercise fatigue. Participants completed 2 acute bouts of resistance exercise (T1 and T2) separated by 2-week ingestion of SUP or control (CON). Outcome measures were assessed pre- and postexercise. When collapsed across groups, a significant decrease in RT performance was seen in the 60-second reaction drill from pre- to postexercise at T1. All other RT tests were similar from pre- to postexercise at T1. Reaction time was not significantly changed by PS. When collapsed across groups, a significant increase in performance of the serial subtraction test was seen. A significant increase (8.9% and 7.1%) in the number of correct answers and a significant decrease (8.0% and 7.5%) in time to answer were seen from pre- to postworkout at T1 and T2, respectively. A significant increase in total MD score from pre- to postworkout was observed for CON but not for PS at T2. Phosphatidylserine significantly attenuated pre- to postexercise perception of fatigue compared to CON. Ingestion of SUP for 14 days appears to attenuate postexercise MD scores and perception of fatigue, but does not affect CF or RT, in recreationally trained individuals.

1. Introduction

Phosphatidylserine (PS) is an endogenously synthesized phospholipid. Phospholipid bilayers form the core structure of the membranes that surround mammalian eukaryotic cells. The distinct lipid composition defines the thickness, permeability, and fluidity of the membrane [1], regulating the properties of the proteins embedded within it [2] and the subsequent activation of cell signaling pathways for specific cellular processes [3]. Consequently, different tissues and different cell types have distinct phospholipid compositions. Despite its ubiquitous distribution, PS it is found predominantly in the

Abbreviations: 1-RM, 1-repetition maximum; CF, cognitive function; CON, Control; D2, Dynavision D2 Visuomotor Training Device; HPL, Human Performance Laboratory; ICC, intraclass correlation coefficient; MD, mood; POMS, Profile of Mood States Questionnaire; PS, phosphatidylserine; RT, reaction time; SEM, standard error of measurement; SST, serial subtraction test; SUP, supplement; T1, testing session 1; T2, testing session 2; TMS, total mood score.

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myelin of brain tissue [4] and appears to have a concomitant role in the activity of nerve cells [5]. Phosphatidylserine is the most effective phospholipid in the activation of classic isoforms of the enzyme protein kinase C [6], triggering the transcription, differentiation, proliferation, and regulation of nerve cells downstream of its activation [7]. In addition, it has been suggested that PS can affect the exocytosis of neurotransmitters through its calcium-dependent interaction with membrane-binding proteins, enhancing the fusion between synaptic vesicles and membranes to release neurotransmitters such as acetylcholine [8]. Consequently, the integration of supplemental PS into cell membranes may stimulate neural amplification, possibly augmenting both cognition and motor function [9,10].

The potential neural benefit has led to investigations examining the effects of PS supplementation on cognition, reaction time (RT), and acute physiological response to both physical and mental stress [11–17]. Acute ingestion of a multi-ingredient supplement containing 50 mg PS in combination with several other nutrients (α-glycerophosphocholine; choline bitartrate; vitamins B3, B6, and B12; folic acid; L-tyrosine; anhydrous caffeine; acetyl-L-carnitine; and naringin) has been shown to maintain RT to both visual and auditory stimuli and focus, following a high-intensity bout of exhaustive exercise [12]. In addition, supplementation with 400 mg/d of PS for 14 days has been shown to significantly increase cognitive function before and 60 minutes postexercise in resistance-trained college-aged men [17], whereas 200 mg/d of PS for 6 weeks in healthy men has been shown to significantly attenuate β-1 power (an indicator of activation associated with cognitive task demands and higher neurophysiological function in right hemispheric frontal brain regions) before and after induced mental stress [11]. Dosages of 800 mg/d PS for 10 days have been reported to significantly blunt the adrenocorticotropic and cortisol response to exercise [16], and supplementation with 750 mg/d for 10 days has been shown to increase time to exhaustion in both runners [13] and cyclists [14]. In contrast, there are several studies that were unable to support any cognitive or ergogenic benefit from PS ingestion. Kingsley and colleagues [15] reported that 750 mg/d for 10 days was not effective in attenuating markers of muscle damage, inflammation, or oxidative stress following prolonged downhill treadmill running. Baumeister and colleagues [11] reported that, following 42 days of supplementation with 200 mg/d of PS, no improvements in cognitive task performance following a mental stress were observed. Other investigators reported no effect on memory or other cognitive functions in older individuals with memory complaints supplemented with 300 or 600 mg/d PS [18]. Consequently, the efficacy of PS remains equivocal.

The differences in these studies may be related to the level of fatigue associated with the protocol. It appears that studies that involved a fatiguing exercise protocol demonstrated a potential ergogenic role for PS, whereas studies that did not exhaust their participants remained equivocal. Considering the apparent role of fatigue on the efficacy of PS, the purpose of this study was to examine the effects of a multi-ingredient supplement on measures of cognitive function, RT, and mood following an acute exhausting resistance exercise protocol. We anticipated declines in cognitive function, RT, and mood state from pre- to postexercise. Therefore, it was hypothesized that these declines would be attenuated through supplementation with PS and caffeine. Specifically, we hypothesized that 14 day of supplementation with PS and caffeine would maintain preexercise cognitive function and RT scores following resistance exercise, and attenuate postexercise fatigue level. To test this hypothesis, we used a double-blind, randomized, controlled trial in which 21 healthy recreationally trained men and women consumed either a multi-ingredient supplement containing 400 mg/d PS and 100 mg/d caffeine, or control for 14 days. Analysis of cognitive function, RT, and mood state was quantified through an objective measure using the serial subtraction test (SST), Dynavision D2 (D2), and Profile of Mood States Questionnaire (POMS) respectively.

2. Methods and materials

2.1. *Participants*

Twenty-two healthy participants (18 men, 4 women) volunteered to participate in this randomized, double-blind, controlled study. One participant was excluded because of nonadherence to the supplementation protocol. Twenty-one participants completed the study (17 male, 4 female; age: 22.5 ± 3.4 years; height: 1.76 ± 1.0 m; weight: 77.6 ± 12.6 kg; body fat: 14.6% ± 6.6%). Following an explanation of all procedures, risks, and benefits associated with the experimental protocol, each participant gave his or her written informed consent to participate in this study. The research protocol was approved by the University of Central Florida Institutional Review Board. All volunteers had at least 6 months of resistance training experience before the initiation of the investigation. Volunteers were not permitted to use any additional nutritional supplementation before and during the investigation. Screening for supplementation use was accomplished via a health questionnaire filled out during volunteer recruitment.

2.2. *Experimental protocol*

Participants reported to the Human Performance Laboratory (HPL) on 2 separate occasions. The study's protocol is depicted in Fig. 1. Each testing session was separated by 2 weeks. Volunteers were instructed to refrain from any strenuous physical activity for 72 hours before testing. In addition, participants were instructed not to drink or eat for 2 hours before each trial. During the first testing session (T1), participants performed a standardized warm-up consisting of 10 minutes of cycling and warm-up sets in both the squat and bench press exercise at 40% to 60% of his/her tested 1-repetition maximum (1-RM). Immediately following the warm-up, participants completed tests of RT (D2) and cognitive function (SST) and a mood survey (POMS). Immediately following these assessments, participants performed an acute bout of resistance exercise. The reaction, cognition, and mood assessments were administered in identical fashion immediately following the resistance training session. Participants were then randomly provided either the supplement (SUP) or control (CON) to ingest for the next 14 days. Participants then returned to the HPL at the end of the 2-week supplement period (T2) and

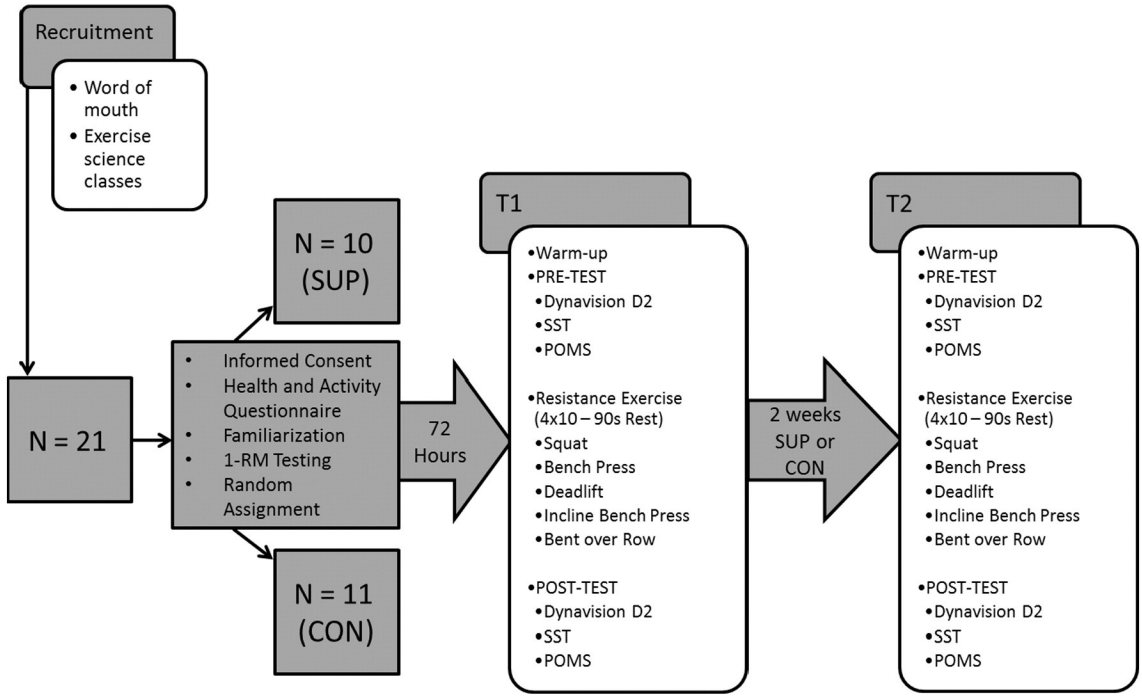

Fig. 1 – Schematic of the experimental protocol. CON, n = 11; SUP, n = 10.

repeated the assessment and exercise protocol conducted during T1. All assessments and exercise programs occurred at the same time of day. The SUP and CON were not provided to participants on the day of testing at T1 and T2 to limit the potential acute effects of caffeine on performance outcomes and avoid ingestion of the supplement in 1 sitting. The duration of time between consuming the last dose and T2 assessment ranged from 12 to 24 hours (average, 17 hours).

2.3. *Familiarization*

Before the onset of the study, all participants were familiarized with the reaction and cognitive assessments. Seven familiarization trials were performed. The first trial consisted of an explanation of all procedures for performing each assessment and a practice test for each assessment. Volunteers then completed 6 additional trials of each assessment to reduce a potential training effect during the study. On the final trial, tests were completed in an identical configuration as would be performed during testing to familiarize them with the complete process. Intraclass correlation coefficients ($ICC_{3.1}$) and standard error of measurements ($SEM_{3.1}$) between the final 2 trials of the familiarization process were calculated for each test to determine internal test-retest reliability, as recommended by Weir [19]. Minimum acceptable ICCs for the testing instruments were set at 0.75 based upon the recommendations of Portney and Watkins [20].

2.4. *Anthropometric and maximum strength testing*

Before maximum strength testing, anthropometric measurements, including height, body mass, and body fat percentage, were recorded. Body mass (±0.1 kg) and height (±0.1 cm) were measured using a Health-o-meter Professional (Patient Weighing Scale, Model 500 KL; Pelstar, Alsip, IL, USA). All body composition measures were performed using standardized procedures previously described for collecting skinfold measurement from the triceps, suprailiac, abdomen, and thigh [21] and previously published formulas for calculating body fat percentage [22]. All measurements of skinfold were performed by the same researcher using the same pair of skinfold calipers (Caliper-Skinfold-Baseline, Model #MDSP121110; Medline, Mundelein, IL, USA).

The 1-RM tests for the squat and bench press exercise were performed using methods previously described by Hoffman [21]. Each participant performed a warm-up set using a resistance that was approximately 40% to 60% of his perceived maximum and then performed 3 to 4 subsequent trials to determine the 1-RM. A 3- to 5-minute rest period was provided between each trial. Bench press testing was performed in the standard supine position: the participant lowered an Olympic weightlifting bar to midchest level and then pressed the weight until his elbows were fully extended. The squat exercise required each participant to descend to the parallel position that was attained when the greater trochanter of the femur reached the same level as the knee. The participant then ascended until full knee extension. A research assistant was used to ensure that participants reached the parallel position for each repetition of the squat. The same research assistant was used for each participant to ensure that the exercise technique was consistent between sessions. Maximum strength testing was administered by a Certified Strength and Conditioning Specialist.

2.5. *Resistance exercise workout*

The resistance exercise workout consisted of the squat, bench press, deadlift, incline bench press, and bent-over row

exercises. Participants were required to complete 4 sets of 10 to 12 repetitions for each exercise, with 90 seconds of rest between each set and 120 seconds of rest between exercises. The resistance workout was administered in the HPL under the supervision of a Certified Strength and Conditioning Specialist. Workout intensity was set at 70% of the participant's 1-RM in the core exercises (bench and squat). Selection of the appropriate loads for the assistance exercises (deadlift, incline bench press, and bent-over row) was based upon the participant's perceived 10-repetition maximum. Resistance was adjusted at T1 to maintain appropriate technique, load, and the desired exercise volume (4 sets × 10–12). A workout log was recorded at T1 and T2. The workout log at T1 subsequently became the standard for the workout at T2.

2.6. *Reaction tests*

Reaction time was assessed using the D2 (Dynavision International LLC, West Chester, OH, USA) as previously described by Hoffman et al [23]. Briefly, the D2 is a light-training reaction device developed to train sensory motor integration through the visual system (Fig. 2). It consists of a board (4 ft × 4 ft) that can be raised or lowered relative to the height of the operator. It contains 64 target buttons arranged into 5 concentric circles surrounding a center screen that can be illuminated to serve as a stimulus for the participant. For each test, the participant stood in front of the board with the center screen at eye level and so that the outermost of the buttons were within reach. A total of 3 different reaction tests were conducted.

The first assessment measured the participant's visual ($ICC_{3.1}$: 0.83; $SEM_{3.1}$ = 0.021), motor ($ICC_{3.1}$: 0.79; $SEM_{3.1}$: 0.049), and physical RT ($ICC_{3.1}$: 0.94; $SEM_{3.1}$: 0.051) to a 4-choice stimulus with the dominant hand. The test was initiated when a participant placed and held his/her hand on an illuminated "home" button. At this point, a single button would light up (visual stimulus) in 1 of 4 locations adjacent to the "home" button on the same horizontal plane. Once the participant recognized the stimulus, he or she was required to leave the "home" button, strike the stimulus, and return back to the "home" button as quickly as possible. This was repeated 10 times per assessment.

The second assessment measured the participant's ability to react to a stimulus as it changed positions on the board. An initial stimulus would present on the D2 in a random location. The stimulus remained lit until it was struck by the participant. The stimulus would then appear at another random location. The participant was instructed to successfully identify and strike as many stimuli as possible within 60 seconds. The number of hits ($ICC_{3.1}$: 0.80; $SEM_{3.1}$: 5.59) and the average time per hits ($ICC_{3.1}$: 0.80; $SEM_{3.1}$: 0.04) was recorded for each participant.

The third assessment was similar to the previous measure in that participants were required to react to a visual stimulus as it changed positions on the board. The difference between the 2 assessments was that the stimulus remained for 1 second before it changed to another random location, and the participant had to verbally recite a 5-digit number that was presented on the center screen of the D2 during each assessment. The 5-digit number was presented a total of 11 times throughout the 60-second test and remained for 0.75 second each time. The appearance of the digits placed an additional demand on the information processing resources of the participant. The participant was instructed to successfully identify and strike each stimulus before it changed position and score as many strikes as possible within 60 seconds. The number of successful hits ($ICC_{3.1}$: 0.82; $SEM_{3.1}$: 6.83) was recorded for each participant.

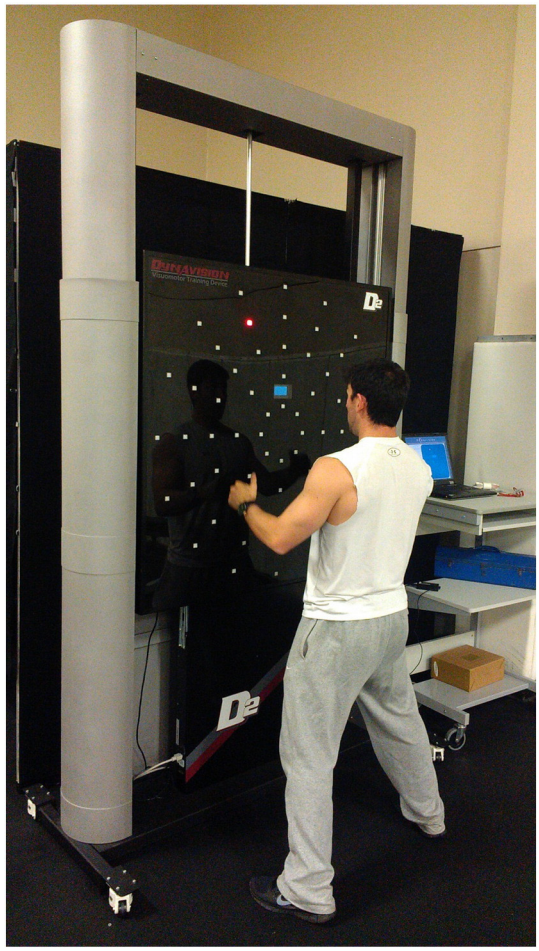

Fig. 2 – Representative image of the Dynavision D2 Visuomotor Device. The D2 is a light-training reaction device. It consists of a board (4 ft × 4 ft) that can be raised or lowered relative to the height of the operator. It contains 64 target buttons arranged into 5 concentric circles surrounding a center screen that can be illuminated to serve as a stimulus for the participant. Reaction time is measured to the nearest 1/100 of a second via attached computer software.

2.7. *Cognitive function*

A modified version of the original Serial Sevens Test [24] was used to analyze cognitive function. This test consisted of a 2-minute timed oral test in which participants were required to subtract the number 7 from a random computer-generated 4-digit number to measure how quickly and accurately they can compute a simple mathematical problem. The computer-generated numbers were written onto standard note cards. Participants were given a randomized stack of note cards

and asked to complete as many calculations as possible in the 2-minute period. Participant and scorer sat opposite each other during testing. The answers to the calculations were written on the back of the note cards in pencil for the scorer to see. Participants were unable to see the correct answer. Once the participants released the note card, their answer was considered unchangeable. The number of correct answers ($ICC_{3.1}$: 0.86; $SEM_{3.1}$: 4.21) and the average time per correct answer ($ICC_{3.1}$: 0.81; $SEM_{3.1}$: 0.81) were recorded.

2.8. Mood

Analysis of mood was performed through the administration of the POMS [25] The POMS consists of 58 words or phrases in a Likert format questionnaire that provides measures of specific mood states. It provides measures of tension, depression, anger, vigor, fatigue, and confusion. A total mood score (TMS) was calculated by subtracting vigor from the sum of the 5 other negative measures and adding 100 to avoid a negative result. Measures of consistency ranging between 0.85 and 0.95 and test-retest reliability estimates ranging between 0.65 and 0.74 have been previously reported for the POMS instrument [25].

2.9. Supplement

The multi-ingredient (SUP) supplement and the control came in the form of a candy chew (Nutravail Technologies, Chantilly, VA, USA), identical in taste and appearance and only distinguishable through the color of the wrapper. Participants were required to consume 4 chews per day, spread out evenly across the day. The SUP contained 100 mg of PS, 25 mg of caffeine, 7 mg niacin, 15 mg vitamin C, 0.38 mg vitamin B1, 2.5 mg vitamin B5, 0.5 mg vitamin B6, 3 IU vitamin E3, 25 mg calcium, 10 mg magnesium, and 4 g of carbohydrates per chew (a total of 400 mg/d PS and 100 mg/d of caffeine per day). The carbohydrates were in the form of evaporated cane juice, brown rice syrup, and rice syrup solids. The composition of CON was identical to SUP with the exception of PS and caffeine content; CON contained no PS or caffeine. Samples were independently analyzed by a third-party laboratory (Covance Laboratories Inc, Madison, WI, USA).

2.10. Statistical analyses

Statistical analysis of the data was accomplished using a 2 × 2 (time × treatment) repeated-measures analysis of variance at T1 and T2. In the event of a significant F ratio, Bonferroni post hoc tests were used for pairwise comparisons. A criterion α level of $P \leq .05$ was used to determine statistical significance. Data are presented as means ± SD. A sample size of 18 yielded a statistical power of 0.99 based upon previously reported data [17] and the methodology of Gravettier and Wallnau [26].

3. Results

3.1. Reaction time

Performance in the reaction drills are depicted in Table 1. No significant differences were seen in visual, motor, or physical RT from pre- to postworkout at T1 ($P = .853$, $P = .224$, and $P = .294$, respectively) or T2 ($P = .502$, $P = .841$, and $P = .646$, respectively). When collapsed across groups, the number of strikes decreased ($P = .054$) from pre- to postworkout at T1, whereas the average time per strike in the 60-second reaction drill tended to increase ($P = .066$). No significant interaction was noted between the groups at T1. There were no significant differences from pre- to postworkout at T2 in either group. When a cognitive stress was added to the 60-second reaction drill, no significant change was seen in either group from pre-

Table 1 – Presupplementation (T1) and postsupplementation (T2) values for 3 RT tests immediately pre- and postworkout

Test	Measure		T1		T2	
			Pre	Post	Pre	Post
			Means ± SD	Means ± SD	Means ± SD	Means ± SD
4-choice RT	Visual RT (s)†	CON	0.37 ± 0.04	0.36 ± 0.04	0.36 ± 0.04	0.35 ± 0.04
		SUP	0.34 ± 0.05	0.34 ± 0.06	0.33 ± 0.04	0.33 ± 0.04
	Motor RT (s)†	CON	0.22 ± 0.04	0.23 ± 0.06	0.19 ± 0.04	0.19 ± 0.04
		SUP	0.23 ± 0.05	0.26 ± 0.07	0.25 ± 0.07	0.25 ± 0.06
	Physical RT (s)†	CON	0.58 ± 0.04	0.59 ± 0.07	0.56 ± 0.05	0.54 ± 0.05
		SUP	0.57 ± 0.07	0.60 ± 0.11	0.58 ± 0.09	0.58 ± 0.06
60-s reaction test	Strikes‡	CON	89.5 ± 10.7	83.6 ± 12.2*	92.6 ± 7.8	89.5 ± 12.8
		SUP	91.7 ± 7.9	89.4 ± 10.5*	92.5 ± 9.3	91.5 ± 8.5
	Ave. time per strike (s)†	CON	0.68 ± 0.08	0.72 ± 0.12	0.64 ± 0.05	0.68 ± 0.12
		SUP	0.66 ± 0.06	0.68 ± 0.08	0.65 ± 0.07	0.65 ± 0.06
60-s reaction test w/ cognitive stressor	Strikes‡	CON	75.1 ± 14.8	70.9 ± 12.7	80.5 ± 9.7	78.9 ± 16.9
		SUP	78.1 ± 12.4	76.4 ± 12.9	81.0 ± 8.7	82.4 ± 9.5

All values presented as means ± SD.
CON, n = 11; SUP, n = 10).
* Main effect for time; $P \leq .05$ when collapsed across groups.
† Reaction time values expressed in 1/100 of a second.
‡ Values expressed as the number of strikes attained within 60 seconds.

to postworkout in the number of strikes at T1 ($P = .227$) or T2 ($P = .959$).

3.2. Cognitive function

Serial subtraction test data are presented in Table 2. When collapsed across groups, a significant increase in the number of correct answers was seen pre- to postexercise at both T1 ($P = .004$) and T2 ($P = .004$). In addition, a significant decrease in time to answer was also seen at T1 ($P = .007$) and T2 ($P = .018$). No differences were noted between groups at either T1 or T2 in any of the SSTs.

3.3. Profile of mood states

Changes in the POMS are seen in Table 3. When collapsed across groups, a significant main effect for time was observed at T1. An increase in TMS ($P = .000$), fatigue ($P = .000$), tension ($P= .034$), and depression ($P = .048$), with a significant decrease in vigor ($P = .021$), was noted from pre- to postworkout. No changes were noted in confusion and anger ($P = .438$ and $P = .962$, respectively). There was a significant interaction for vigor at T1 from pre- to postworkout for SUP compared to CON ($P = .035$). A significant decrease in vigor was observed in the CON group ($P = .007$); however, no significant change was observed in the SUP group ($P = .857$). A significant interaction ($P = .034$) for TMS was observed at T2. Post hoc analysis demonstrated a significant increase in TMS for CON ($P = .003$); however, no significant change was observed for SUP ($P = .166$). Significant elevations in fatigue were observed in CON ($P = .00$) and SUP ($P = .016$) following the workout at T2. However, significant interaction ($P = .031$) indicates that the magnitude of change in fatigue was greater in CON (+29%) compared to SUP (+16%). A significant decrease in confusion was observed in SUP ($P = .041$), but not CON ($P = .387$), at T2. However, no interaction was observed between the groups ($P = .336$). No changes from preexercise were observed in either group at T2 for vigor, depression, or anger.

4. Discussion

Results of this study indicate that ingestion of 400 mg/d of PS and 100 mg/d caffeine for 14 days attenuates postexercise mood scores and perception of fatigue. Participants ingesting PS were able to maintain TMS from pre- to postexercise, whereas participants consuming a control experienced a significant increase in total mood disturbance. In addition, perception of fatigue from pre- to postexercise was significantly attenuated in participants ingesting PS. An acute bout of resistance exercise appears to improve cognitive performance; however, PS provides no further benefit. Supplementing with PS does not appear to improve RT.

The purpose of this study was to examine the effects of PS. Consequently, every effort was made to minimize the effects of the other ingredients. The vitamin, mineral, and carbohydrate composition of SUP was identical to that of the CON, negating a possible ergogenic role for these ingredients in SUP. In addition, SUP was not provided to participants on test days at T1 or T2. The short 4-hour half-life of caffeine [27] and the 12- to 24-hour time lapse between ingestion of the last dose and testing at T2 minimized any potential acute ergogenic effects from caffeine. It has been suggested that the potential effects of caffeine and caffeine-containing supplements are negated by the build-up of a tolerance during chronic caffeine ingestion [12,28]. Consistent with this, previous research has shown that measures of cognition, RT, psychomotor task performance, and all mood constructs of the POMS questionnaire, with the exception of vigor, are unaffected following 11 days of chronic caffeine ingestion at dosages of 0, 3, and 6 $mg \cdot kg \cdot day^{-1}$ [28]. Our results showed that vigor and all other mood constructs were not significantly different between preworkout assessments at T1 and T2. It is therefore most likely that the results observed in the currently study were due to the effect of PS.

The current study design was based on a previous investigation by Parker et al [17] that demonstrated efficacy of chronic PS ingestion following an acute resistance exercise workout. Both studies used a similar dosing scheme, but there was a difference in the exercise protocol. In the present study, a whole-body workout was performed, whereas Parker and colleagues [17] used a lower-body–only exercise routine. Although their protocol resulted in significant fatigue, we decided to incorporate a whole-body workout because of the upper-body reaction tests that were being measured. Others have demonstrated an inhibition of sensorimotor [29,30] and neuromuscular function [31] following an acute bout of resistance exercise. Consequently, we expected to see

Table 2 – Presupplementation (T1) and postsupplementation (T2) values for SST immediately pre- and postworkout

Test	Measure		T1		T2	
			Pre	Post	Pre	Post
			Means ± SD	Means ± SD	Means ± SD	Means ± SD
SST	No. of correct answers †	CON	34.2 ± 8.8	36.3 ± 10.5 *	36.8 ± 12.1	39.3 ± 11.6 *
		SUP	30.7 ± 9.3	34.5 ± 9.5 *	32.8 ± 9.6	35.3 ± 10.3 *
	Ave. time per answer (s) ‡	CON	3.8 ± 1.1	3.6 ± 1.1 *	3.8 ± 1.6	3.4 ± 1.5 *
		SUP	4.2 ± 1.3	3.8 ± 1.1 *	3.9 ± 1.0	3.7 ± 1.1 *

All values presented as means ± SD.
* Main effect for time; $P \leq .05$ when collapsed across groups.
† Total number of correct answers in 2-minute timed SST.
‡ Average time per correct answer in 2-minute timed SST (120 seconds/# correct) expressed in seconds.

Table 3 – Presupplementation (T1) and postsupplementation (T2) values for POMS constructs pre- and postworkout

Test	Mood construct		T1		T2	
			Pre	Post	Pre	Post
			Means ± SD	Means ± SD	Means ± SD	Means ± SD
POMS	TMS	CON	231.7 ± 18.5	260.5 ± 16.6*	227.3 ± 12.8	254.2 ± 20.6*†
		SUP	233.6 ± 9.3	249.3 ± 13.1*	234.5 ± 10.2	241.8 ± 13.7*
	Fatigue	CON	38.9 ± 6.9	54.2 ± 9.7*	36.5 ± 5.6	51.7 ± 9.5*†
		SUP	35.7 ± 3.4	47.9 ± 8.4*	38.0 ± 4.9	45.1 ± 7.6*
	Tension	CON	39.0 ± 3.8	41.5 ± 6.1*	35.5 ± 4.1	39.3 ± 7.7
		SUP	39.4 ± 6.0	42.8 ± 8.7*	38.5 ± 5.4	38.1 ± 4.0
	Vigor	CON	56.4 ± 13.7	45.2 ± 9.9*†	52.8 ± 14.5	44.4 ± 12.8
		SUP	52.8 ± 13.5	52.2 ± 17.7	52.5 ± 12.3	50.6 ± 14.1
	Depression	CON	37.0 ± 0.0	37.3 ± 0.5*	37.0 ± 0.0	37.18 ± 0.4
		SUP	37.0 ± 0.0	37.1 ± 0.3*	37.0 ± 0.0	37.0 ± 0.0
	Confusion	CON	35.2 ± 1.4	35.1 ± 2.7	33.6 ± 2.4	33.0 ± 1.8
		SUP	35.8 ± 3.4	34.9 ± 3.6	35.3 ± 2.4	33.7 ± 3.2*
	Anger	CON	38.0 ± 1.6	37.7 ± 1.3	37.5 ± 1.3	37.4 ± 0.8
		SUP	38.5 ± 2.4	38.8 ± 2.6	38.2 ± 2.0	38.5 ± 2.4

All values presented as means ± SD.
Scores for questionnaire adjectives representing each mood construct were added together to give a total score for that construct. This score was then converted to a T-score using a conversion table. Data are represented as a T-score for each construct.
* Main effect for time; $P \leq .05$ when collapsed across groups.
† Between-groups interaction, $P \leq .05$.

significant decreases in RT in response to the exercise protocol. Consistent with previous research, significant declines in the number of strikes for the 60-second reaction drill and a trend toward a decrease in RT following the addition of a cognitive stress were observed. However, visual and motor reaction to a visual stimulus was not significantly affected by the acute bout of exercise. This may be related in part to the complexity of the task. Analysis of visual and motor RT was shorter in duration and localized to a much smaller section of the board. It is possible that this task may have placed less demand on the sensorimotor system, perhaps negating the effects of fatigue. This is consistent with others who reported no changes in motor performance or RT following strength workouts varying in time between 30 and 60 minutes [32,33].

Our results indicate that PS has no effect on RT. This appears to be consistent with others investigating the effects of PS on RT [12,18,34]. Hoffman and colleagues [12] reported no change in postexercise RT following 4 weeks of PS ingestion (50 mg/d), whereas Jorissen et al [18] saw no significant differences in RT between individuals consuming either 300 or 600 mg/d PS for 12-weeks and those consuming placebo. In addition, Richter et al [34] found no improvements in simple or choice RT following 6 weeks of supplementation with 300 mg/d PS and docosahexaenoic acid. The evidence supporting the efficacy of PS ingestion and improved RT to a visual stimulus is therefore lacking.

Previous studies have shown that ingestion of 300 mg/d PS for 12 and 24 weeks, respectively, can significantly enhance cognition in older adults [35,36]. In the present study, we were unable to support the efficacy of 2 weeks of PS ingestion on cognitive performance. Differences could be related to duration of ingestion as well as to differences in participant population. Previous studies have used older adults with cognitive decline who may exhibit a greater potential for effect than that seen in a younger, healthier population.

There have been only a few investigations that have examined the effect of PS in a young population [10,11,17]. Baumeister et al [11] reported that 6 weeks of ingesting 200 mg/d PS had no effect on cognitive function in healthy college-aged men, whereas Kennedy et al [10] observed significant increases in memory task performance in healthy college-aged men and women following an acute ingestion of 360 mg PS complexed with 120 mg ginkgo biloba, an effect not seen with ginkgo biloba alone. To our knowledge, only 1 study has observed significant improvements in a young healthy population following prolonged PS ingestion. Parker et al [17] reported that 400 mg/d PS for 14 days can significantly improve the number of correct answers and time to answer the SST before acute resistance exercise and time to answer 60 minute postexercise, whereas acute resistance exercise had no effect on cognitive performance immediately following exercise. In the present study, significant increases in cognitive performance following exercise were observed across both groups at T1 and T2, suggesting that the exercise intervention augmented cognitive performance and that PS provided no additional benefit. Cue utilization theory suggests that the relationship between exercise and cognitive performance operates on an inverted 'U' basis, whereby moderate-intensity exercise could improve cognitive performance, whereas high-intensity exercise would lead to a decrease in cognitive performance [37]. This is consistent with the moderate-intensity, high-volume exercise protocol used in both the present study and that by Parker et al [17]. Nevertheless, the effects of PS on cognitive performance in a young population remain equivocal.

It appears that PS may be effective in enhancing mood only when a mental or physical stress is present. With the exception of Parker et al [17], who found no significant changes in baseline or postexercise mood scores in physically active college-aged men, other studies using a mental or physical

stressor have found similar effects. Participants consuming a 400-mg/d complex of PS and phosphatidic acid for 3 weeks showed decreased levels of distress in response to a mental stress, as measured by the Spielberg State Anxiety Inventory Stress subscale [38]. Others have reported that 6 weeks of supplementation with 200 mg/d PS has been shown to significantly decrease β-1 power in right hemispheric frontal brain regions before and after induced stress in healthy male participants, an indication of increased relaxation [11]. In addition, ingestion of 300 mg/d PS for 1 month has been associated with improved mood and decreased stress in young adults with above-normal neuroticism scores following an acute mental stressor [39]. In contrast, when a physical or mental stressor is not present, PS supplementation does not appear to benefit mood [34]. Our findings showed significant improvements in postexercise mood state and perception of fatigue following PS supplementation, as measured by the POMS. These findings add important new data regarding PS as a consumer supplement. It appears that PS supplementation may be most effective for mood improvements when there is apparent mood impairment, but may not be as effective for individuals who are in a positive or healthy mood state. Based upon our results and previous research [11,34,38,39], consumers who are not experiencing a negative mood state or periods of substantial fatigue may not benefit from supplemental PS. However, supplemental PS may have implications in arenas where substantial fatigue or impaired mood is present.

The major limitation of this study involves the combination of both PS and caffeine as the active ingredients. As a result, we do not have the ability to delineate between the effects of these 2 ingredients. However, considering the physiological role of caffeine, we feel that any benefits from the supplement were primarily the result of PS. Another limitation of the study was that a crossover design was not used. Considering that there are limited data regarding a washout period for PS, a crossover design was not deemed to be feasible.

In conclusion, the results of this study indicate that daily ingestion of a supplement containing 400 mg/d PS and 100 mg/d caffeine may be effective for attenuating total mood disturbance and perception of fatigue following an acute exercise stress. As a result, our hypothesis was only partly verified, as there was an expected attenuation of postexercise fatigue following 14 days of supplementation. However, we reject the hypothesis that a multi-ingredient supplement containing PS and caffeine would attenuate fatigue-induced declines in RT and cognition. Phosphatidylserine supplementation does not appear to significantly improve RT or cognitive function in a young resistance-trained population after 2 weeks of supplementation. However, an acute bout of whole-body moderate-intensity resistance exercise alone may enhance cognitive performance.

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