RELATIONSHIP BETWEEN PHYSICAL ACTIVITY PARTICIPATION AND RECOVERY OUTCOMES IN COLLEGE-AGED ADULTS WITH A CONCUSSION

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Relationship Between Physical Activity Participation and Recovery Outcomes in College-Aged Adults with a Concussion

ABSTRACT

Context: Previously, the most common treatment for a concussion was prolonged physical and cognitive rest. Recent research suggests that earlier physical activity (PA) may be better at promoting recovery. Research has not evaluated the relationship between free-living PA (e.g., walking) and symptom reporting or recovery duration.

Objective: To assess the relationship between free-living physical activity (PA) participation and two recovery outcomes in college-aged adults with a concussion.

Design: Prospective Cohort

Setting: Division 1 & 3 Universities

Participants: Thirty-two college-aged adults (68.8% female, age: 19.8±1.4) with a concussion.

Main Outcome Measures: Participants completed a post-concussion symptom evaluation at visits 1 (<72 hours from concussion) and 2 (8 days later). Between visits, participants’ PA was monitored using an Actigraph GT9X Link PA monitor and expressed as total PA (counts per minute) and percent time of PA spent in moderate-to-vigorous intensity (%MVPA). Recovery time was the number of days from injury occurrence to medical clearance. Separate hierarchical multiple regressions evaluated the relationship between total PA and each recovery variable (visit 2 symptom severity, recovery time). Additionally, separate exploratory hierarchical multiple regressions evaluated the relationship between %MVPA and each recovery variable. Statistical significance was set a priori at $p \leq .05$. 
Results: Participants averaged 2446±441 counts per minute and spent 12.1±4.2% of their PA performing MVPA. Participants yielded median symptom severities of 28[24] and 2[8] for visit 1 and 2, respectively. Average recovery time was 14.7±7.5 days. Total PA did not significantly contribute to the model for visit 2 symptom severity ($p=.122$) or recovery time ($p=.301$).

Similarly, %MVPA had little contribution to the model for visit 2 symptom severity ($p=.358$) or recovery time ($p=.276$).

Conclusion: Results suggest that free-living PA may not be enough to reduce symptoms or shorten recovery. Thus, clinicians may need to provide patients with more structured PA protocols mimicking previous research.

Key Words: Actigraph, symptoms, MVPA

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Key Points:

During the first week after a concussion, 12% of PA completed by college-aged adults was classified as MVPA.

Free-living PA participation during the first week after concussion was not associated with symptom reporting or overall recovery time.
Concussions account for approximately 6% of all injuries in collegiate sports.\(^1\)

Individuals with a concussion may experience an array of symptoms, cognitive impairments, and balance deficits, which typically resolve within two weeks of injury for adults.\(^2\) However, approximately 15% of individuals experience a protracted recovery lasting longer than 30 days.\(^3\) Factors such as sex,\(^4\) age,\(^4\) and previous health history\(^5\) have all been reported to influence concussion recovery time. Additionally, several concussion management techniques have also been found to influence concussion recovery trajectories.\(^6-8\)

For years, healthcare providers emphasized prolonged physical rest until patients were completely asymptomatic, regardless of recovery duration.\(^9\) Physical rest is believed to ease discomfort during the acute recovery phase, minimize the excessive energy demands of the brain, and limit chances of a subsequent head injury.\(^10,11\) Despite these perceived benefits, little research evidence exists supporting the benefits of rest beyond the acute recovery phase. Furthermore, prolonged periods of rest may be associated with delays in symptom resolution and longer recovery time.\(^6,12\) Specifically, Thomas et al.\(^6\) found that extending rest periods by an extra 3 days delayed symptom resolution for 50% of adolescent patients. As a result, researchers have begun investigating more proactive strategies such as incorporating PA earlier in concussion recovery.

Physical Activity has previously been shown to influence various aspects of cognition and symptom reporting following chronic brain disorders.\(^13,14\) These reported findings suggest PA may also have some utility following other conditions of the brain such as a concussion.\(^13,14\)

When implementing a PA protocol early in recovery, researchers found that children with a concussion recovered 3-15 days faster and reported less concussion symptoms than those who were instructed to strictly rest.\(^8,15\) The exercise intensity for these participants was 80% of the
heart rate at which symptoms were exacerbated.\textsuperscript{8, 15} This emphasis on heart rate may suggest that PA intensity is a crucial factor in concussion PA protocols. It should be noted that most concussion PA research includes treadmill- or stationary bike-based protocols, which require direct clinical supervision.\textsuperscript{7, 8, 15} Unfortunately, these types of interventions are not clinically feasible for all healthcare professionals due to a lack of resources, training, and time. Thus, identifying a more clinically feasible approach, such as increasing daily free-living PA, may be sufficient for improving concussion recovery outcomes.

Researchers have quantified free-living PA participation (e.g., walking) in youth athletes after a concussion.\textsuperscript{16, 17} One investigation found an immediate reduction in the average daily step counts of concussed high school and collegiate athletes compared to healthy controls (6,663 vs 11,148 steps per day).\textsuperscript{17} Despite this initial decline, athletes with a concussion slowly returned to similar activity levels as their healthy counterparts over the course of their recovery.\textsuperscript{17} Another study found that higher post-concussion PA was associated with significantly fewer vestibular symptoms after injury.\textsuperscript{16} These preliminary findings suggest a possible association between free-living PA participation and aspects of concussion recovery. However, this potential link has only been evaluated in youth athletes on a single vestibular assessment. Further research is needed to evaluate this concept in an older population (i.e., college-aged adults), as well as to evaluate the influence of this type of PA on other indicators of concussion recovery (i.e., symptom reporting and recovery time). Therefore, the purpose of this study was to assess the relationship between free-living PA participation and two recovery outcomes in college-aged adults with a concussion. It was hypothesized that adults with greater PA participation would report less concussion symptoms and recover faster than those adults with lower PA participation.

\textbf{METHODS}
Design and Participants

A prospective cohort study design was used to assess the relationship between PA participation and indicators of recovery after a concussion. The current study was approved by the Institutional Review Board prior to data collection. Participants were recruited from a National Collegiate Athletic Association (NCAA) Division I University and a NCAA Division III University. Participants were included in the study if they were between the ages of 18-24 years, diagnosed with a concussion, and completed their first visit within 72 hours of their concussion occurrence. Participants were excluded if they had an additional diagnosed concussion within the past 6 months, were currently taking any central nervous system active prescription medication, had a history of moderate or severe traumatic brain injury, or had a history of brain surgery. Participants with a current cardiovascular disorder or lower extremity injury were also excluded due to their potential impact on PA participation.

Operational Definitions

Concussion

All concussion diagnoses were made by a healthcare professional (e.g., MD, DO) utilizing the operational concussion definition provided by the 5th International Concussion in Sport Group. The International Concussion in Sport Group defines a concussion as a complex pathophysiological process affecting the brain, induced by biomechanical forces. Additionally, the following criteria were used when diagnosing individuals with a concussion: 1) observed and/or reported mechanism of injury; and 2) the presence of at least one or more of the following: a) on-field signs (e.g., disorientation/confusion, loss of consciousness, balance difficulties, amnesia), b) symptoms (dizziness, nausea, headache), and/or c) any impairment on sideline assessments (e.g., SCAT5).
Recovery Time

Participant recovery time was classified as the number of days from injury occurrence to clearance for full unrestricted activity by a healthcare provider (MD, DO, NP). Medical clearance was determined utilizing a multifaceted approach, however was ultimately decided based on the healthcare providers own discretion.

Instrumentation

Post-Concussion Symptom Evaluation

The post-concussion symptom evaluation consists of 22 common post-concussion symptoms (i.e., headache, dizziness, difficulty concentrating, etc.) on a 7-point Likert scale (0 (none) to 6 (severe)). Participants rated these symptoms based on how they felt at the time of their visit. Post-concussion symptom total was represented as the total number of symptoms endorsed out of 22, and symptom severity was calculated by adding the Likert scale scores of all reported symptoms for a max score of 132. This symptom scale has been shown to be a valid tool when assessing individuals for a concussion.\(^\text{18}\)

Actigraph GT9X Link Physical Activity Monitor

Participants were asked to wear an Actigraph GT9X Link physical activity monitor (Actigraph Corp, Pensacola, FL) on their non-dominant wrist between visit 1 and visit 2. Participants were instructed to only remove the monitor during water activities (e.g., bathing, swimming) or any activity that may significantly damage the device. Data acquired from the monitors were collected in raw form with a sample frequency of 30 Hz. The data were processed in 60-second epochs using ActiLife Software (Actigraph Corp, Pensacola, FL). Participants were required to wear the monitor for 7 consecutive days at a minimum of 8 hours per day to be considered valid and usable data. Monitor wear time was validated using the Choi\(^\text{19}\) algorithm.
Actigraph PA monitors have previously been shown to be valid and reliable at measuring PA under free-living conditions in young and active adults.\textsuperscript{20} Additionally, the non-dominant wrist position was chosen to increase patient compliance as this anatomical placement was most preferred by patients in previous research and matched the procedures for the MVPA cutpoints.\textsuperscript{21, 22} To determine \%MVPA, wrist-specific cut points were used to classify intensity as either light PA or MVPA.\textsuperscript{23}

Daily Questionnaire

Participants completed a daily online questionnaire between the first two visits. The questionnaire utilized the Qualtrics platform and took no longer than 3 minutes to complete. This questionnaire asked participants to self-report their total time (in minutes) spent on homework and in class each day. Total cognitive activity was evaluated for its potential impact on symptom reporting or recovery time.

Procedures

Participants with a diagnosed concussion completed their first visit within 72 hours of sustaining their injury. During the first visit, participants provided informed consent, completed personal and injury demographic information, completed the PCSS and were given an Actigraph GT9X Link physical activity monitor. Participants were instructed to wear the device on their non-dominant wrist for 7 consecutive days only to remove it during water-based activities or events that may damage the devices. Physical activity participation was monitored starting no earlier than 48 hours and no later than 72 hours after participant sustained their concussion. This is due to physical rest being recommended for the first 48 hours after injury by current consensus statements.\textsuperscript{2}
Between visit 1 and visit 2 participants completed the Qualtrics questionnaire daily at 8:00pm based on their current day. Participants then returned for their second visit 8 days (±1 day) after visit 1 and again completed the PCSS. After visit 2, participants returned their physical activity monitor to researchers. Participants continued to be managed by their respective healthcare provider until they received full unrestricted medical clearance.

**Data Analysis**

Participants not meeting study wear time requirements (7 days, minimum 8 hours per day) or Choi\(^{19}\) validation recommendations were removed prior to analysis. Descriptive statistics were calculated for demographic information, PA participation and concussion recovery outcomes (symptom reporting, recovery time). A Mann-Whitney \(U\) analysis and an independent samples t-test were utilized to identify any sex differences for concussion recovery indicators and PA participation, respectively.

Separate hierarchical multiple regression analyses were utilized to assess the relationship between total PA (counts per minute) and indicators of concussion recovery (visit 2 symptom severity, recovery time) while accounting for visit 1 symptom severity.\(^4,24\) In addition, participant sex was entered into the symptom reporting model to account for its influence on visit 2 symptom severity.\(^25,26\)

Separate exploratory hierarchical multiple regression analyses were completed to assess the relationship between PA intensity (%MVPA) and the indicators of concussion recovery (visit 2 symptom severity, recovery time). Like the previous analyses, visit 1 symptom severity was entered into the models to account for its influence on visit 2 symptom severity and recovery time. Participant sex was only entered into the symptom reporting model due to its previously reported influence on symptom reporting.\(^25,26\) All statistical analyses were conducted using...
SPSS version 24.0 (IBM Corporation, Armonk, NY). An a-priori alpha level was set at $p = 0.05$
for all analyses.

RESULTS

Demographic Information

A total of 44 college-aged adults with a concussion were enrolled in the current study. Of
the enrolled participants, one participant (2.2%) was later excluded due to not reaching full
medical clearance within the study timeframe. Additionally, 10 participants (22.7%) were
removed for not meeting study wear time requirements (7 days, minimum 8 hours per day)
and/or Choi Actigraph wear time validation requirements. Finally, one participant (2.2%) was
removed from analysis due to their symptom reporting (visit 1 and 2 severity) and recovery time
results being classified as outlier values relative to the distribution among our sample ($z$-score $> 3.0$).

Thirty-two participants (68.8% female, age: 19.8 ± 1.4) were included in our final
analyses. Table 1 includes additional participant demographic information.

(Insert Table 1 Here)

Concussion Outcomes

Females reported a greater symptom severity than males at visit 2 ($U = 51.00, p = .014$).
In addition, a significant relationship was found between visit 1 symptom severity and visit 2
symptom severity ($r_s = .354, p = .044$). Table 2 includes symptom reporting results, whereas
Table 3 shows concussion recovery time for all participants. It should be noted that total minutes
spent in class/studying had no impact on symptom reporting ($r_s = .347, p = .065$) or recovery time ($r_s = .301, p = .112$).

(Insert Table 2 Here)

(Insert Table 3 Here)

Physical Activity

Participant’s PA started being recorded on average 54.5 ± 8.8 hours after sustaining their injury. On average, participants recorded 2446 ± 441 counts per minute and spent 12.1% ± 4.2% of their time in MVPA. Detailed PA results for all participants can be found in Table 4.

(Insert Table 4 Here)

Predictors of Recovery

When evaluating the relationship between total PA and visit 2 symptom severity, participant sex and visit 1 symptom severity were entered into the model first. Step one yielded an overall significant model ($F_{(2,29)} = 7.57, p = .002$), accounting for 34.3% of the variance ($R^2 = .343$). After entering total PA the model remained significant ($F_{(3,28)} = 6.16, p = .002$) and accounted for 39.8% of the variance ($R^2 = .398; R^2$ change = .055). Visit 1 symptom severity was a significant contributor to the final model ($B = .315; 95\% CI: .125, .504; p = .002$), whereas participant sex ($B = 5.58; 95\% CI: -2.53, 13.69; p = .170$) and total PA ($B = -.006; 95\% CI: -.015, .002; p = .122$) were not. No significant findings were found when evaluating the relationship between total PA and recovery time while accounting for visit 1 symptom severity.
An exploratory analysis evaluated the relationship between %MVPA and visit 2 symptom severity. During this analysis, participant sex and visit 1 symptom severity were entered into the model first yielding an overall significant model ($F_{(2,29)} = 7.57, p = .002$) that accounted for 34.3% of the variance ($R^2 = .343$). After adding %MVPA, the model remained significant ($F_{(3,28)} = 5.32, p = .005$) and accounted for 36.3% of the variance ($R^2 = .363$; $R^2$ change = .020). However, %MVPA ($B = -.404; 95\% CI: -1.29, .481; p = .358$) and participant sex ($B = 4.72; 95\% CI: -3.35, 12.97; p = .251$) did not significantly contribute to the model. Visit 1 symptom severity was the only significant contributor to the model ($B = .313; 95\% CI: .117, .510; p = .003$). Similarly, no significant findings were found between %MVPA and recovery time while accounting for visit 1 symptom severity (step 1: $F_{(1,30)} = .12, p = .732; R^2 = .004$; step 2: $F_{(2,29)} = .677, p = .516; R^2 = .045; R^2$ change = .041).

**DISCUSSION**

The purpose of the current study was to evaluate the relationship between PA and symptom reporting and recovery time in college aged adults with a concussion. The included sample of adult participants recorded similar PA results to those found in adolescent with a concussion (2446 vs 2550 counts per minute). These similar findings suggest that free-living PA may be relatively consistent among different age groups during the first week after concussion. However, unlike Sufrinko et al., the current study found no significant changes ($R^2$ change = .020 - .055) to our regression model when adding the PA variables (total PA and %MVPA). Which may have been due to age related recovery differences, or the recovery variables being assessed (symptom severity vs vestibular symptoms). Rather, for the current
study, the only significant contributing factor to either model was visit 1 symptom reporting. In addition, our exploratory analyses revealed no significant models for concussion recovery time. In light of the lack of statistically significant findings, results from the current study suggest that simply modifying free-living PA may not be enough to impact recovery after a concussion.

This study was the first to explore the relationship between Actigraph measured %MVPA and concussion recovery. While performing free-living PA, participants spent 88% of their time performing light activities and only 12% performing MVPA. With participants spending the majority of their time in light PA, it may be concluded that light intensity may not be sufficient enough to induce a therapeutic response after concussion. This intensity insufficiency was also noted by Varner et al.\textsuperscript{27} who found no significant changes in symptoms when implementing a 30-minute light PA regiment after mTBI. Conversely, other previous research has utilized a more structured treadmill-based approach in which participants determine their intensity based on symptom exacerbation.\textsuperscript{7, 8, 15} Due to the individualized approach in determining PA intensity, it is possible that participants in other studies are completing more intense PA compared to the current study. Specifically, Leddy et al.\textsuperscript{7, 15} utilized a 20-minute protocol requiring participants to maintain a heart rate at 80% of their pre-established symptom provoking threshold. Thus, participants may have been able to tolerate PA intensity in moderate-to-vigorous levels. After employing this protocol, researchers found significant recovery time improvements compared to those who did not receive the treatment.\textsuperscript{15} However, our exploratory analysis found no significant relationship between free-living PA intensity (%MVPA) and concussion recovery time. There is a possibility that these conflicting results are due to differences in PA intensity. Unfortunately, our team was unable to examine vigorous PA alone, as the only wrist cut-points that exist (used in this study) do not differentiate between moderate and vigorous PA. Therefore,
future research evaluating PA after a concussion should monitor and report as many PA (i.e.,
mode, duration, frequency, etc.) and patient (i.e., heart rate) details as possible to allow for
comparison between structured and free-living PA. Research is also needed to confirm if meeting
an intensity or movement threshold (i.e., 10,000 steps per day) improves concussion recovery.

Although PA is a promising management technique, there is another factor to consider
that may have also influenced the current study’s findings. A strong social support system has
been shown to be a critical component when recovering from a concussion. Specifically, 89%
and 78% of individuals rely on family and friends for support while recovering from a
concussion, respectively. Moreover, athletes who reported high satisfaction with their support
network had lower anxiety symptoms throughout their concussion recovery. Thus for the
current study, it is possible that sedentary participants spent more of their time seeking social
support after their injury than engaging in PA. While current management practices aim to better
incorporate PA post-injury, the importance of a strong social support network should not be
neglected.

This study was not without limitations. Although 44 participants were enrolled, 12 were
excluded from the final analysis. This yielded a relatively low sample size of 32 participants,
making results challenging to interpret. The use of counts per minute as a measure of PA also
posed a challenge with the generalizability of the current study. In addition, our study lacked a
control group to further make PA comparisons to healthy college-aged adults. Another limitation
of the study is the inability to account for all external factors that may have influenced symptom
reporting or recovery time. Specifically, participants were not asked about social
activities/support or specific cognitive activities (i.e., screen time) that were performed over the
duration of the study. As previously mentioned, we were not able to differentiate between
moderate and vigorous PA due to lack of available cut points. Finally, this pragmatic study utilized multiple health care providers for concussion diagnosis and management. Researchers found it unreasonable to ask clinicians to alter their current clinical practice for the study, thus participants may have received slightly different standards of care or medical clearance criteria.

Despite previous research identifying more structured PA as improving concussion recovery, the current study found no such relationship in a free-living condition. These results suggest that PA intensity may be a modulating factor for concussion recovery. Research is needed directly comparing the effects of different PA intensities and modes on concussion recovery. Although the variable counts per minute is unique to Actigraph and is challenging to directly apply clinically, results from the current study may influence the mode to which PA is applied after concussion. Specifically, when managing patient with a concussion, clinicians may need to provide patients with a specific PA protocol rather than telling them to simply “increase their daily activity”. For example, this may mean providing patients with a specific treadmill or stationary bike protocol that has been previously shown to be beneficial after a concussion.\(^7,15\)
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Table 1: Participant Demographics

| Demographic Variable         | n (%)     |
|------------------------------|-----------|
| Age, M(SD)                   | 19.8 (1.4) |
| Sex                          |           |
| Male                         | 10 (31.3)  |
| Female                       | 22 (68.8)  |
| Academic Class               |           |
| Freshman                     | 9 (28.1)   |
| Sophomore                    | 7 (21.9)   |
| Junior                       | 8 (25.0)   |
| Senior                       | 7 (21.9)   |
| Grad                         | 1 (3.1)    |
| Medical Diagnoses            |           |
| ADHD/ADD                     | 5 (15.6)   |
| Depression/Anxiety           | 7 (21.9)   |
| Previous Concussion          | 17 (53.1)  |
|                         | Visit 1 |                      | Visit 2 |                      |
|-------------------------|---------|----------------------|---------|----------------------|
|                         | Symptom Total | Symptom Severity | Symptom Total | Symptom Severity |
|                         | Mean ± SD  | Median [IQR]        | Mean ± SD  | Median [IQR]        |
| **Sex**                 |          |                      |          |                      |
| Male                    | 11.8 ± 5.5 | 12.5 [9]             | 0.8 ± 1.3 | 0.0 [2]             |
| Female                  | 13.9 ± 4.0 | 13.5 [6]             | 4.8 ± 5.3 | 3.0 [8]             |
| Total                   | 13.3 ± 4.5 | 13.0 [7]             | 3.5 ± 4.8 | 1.5 [6]             |
| **ADHD/ADD**            |          |                      |          |                      |
| No                      | 13.3 ± 4.6 | 13.0 [6]             | 3.4 ± 4.7 | 1.0 [6]             |
| Yes                     | 12.8 ± 4.3 | 14.0 [8]             | 4.2 ± 5.8 | 3.0 [9]             |
| **Depression/Anxiety**  |          |                      |          |                      |
| No                      | 13.0 ± 4.7 | 13.0 [7]             | 3.4 ± 4.4 | 1.0 [6]             |
| Yes                     | 14.0 ± 4.1 | 14.0 [5]             | 4.1 ± 6.2 | 3.0 [2]             |
| **Previous Concussion** |          |                      |          |                      |
| No                      | 13.3 ± 3.4 | 13 [5]               | 5.4 ± 5.9 | 3.0 [9]             |
| Yes                     | 13.2 ± 5.4 | 14.0 [8]             | 1.9 ± 2.8 | 1.0 [3]             |
Table 3: Participant Concussion Recovery Time (Days)

|                          | Mean ± SD | Median [IQR] |
|--------------------------|-----------|--------------|
| **Sex**                  |           |              |
| Male                     | 12.4 ± 6.7| 10.5 [4]     |
| Female                   | 15.7 ± 7.7| 14.0 [9]     |
| **Total**                | 14.7 ± 7.5| 11.5 [9]     |
| **ADHD/ADD**             |           |              |
| No                       | 15.2 ± 7.9| 12.0 [9]     |
| Yes                      | 12.0 ± 3.7| 11.0 [7]     |
| **Depression/Anxiety**   |           |              |
| No                       | 15.1 ± 8.1| 12.0 [10]    |
| Yes                      | 13.1 ± 4.5| 11.0 [6]     |
| **Previous Concussion**  |           |              |
| No                       | 16.1 ± 8.6| 13.0 [6]     |
| Yes                      | 13.5 ± 6.4| 11.0 [10]    |
|                          | Mean (SD)     | Median [IQR]   | Min - Max    |
|--------------------------|---------------|----------------|--------------|
| **% PA in Light Activity |               |                |              |
| Males                    | 89.3% ± 1.9%  | 89.0% [3.0%]   | 86.8% - 92.5%|
| Females                  | 87.7% ± 4.3%  | 89.0% [4.3%]   | 77.7% - 95.5%|
| Total                    | 88.2% ± 3.7%  | 88.6% [5.3%]   | 77.7% - 95.5%|
| **% PA in MVPA**         |               |                |              |
| Males                    | 10.7% ± 1.9%  | 11.0% [3.0%]   | 7.5% - 13.3% |
| Females                  | 12.3% ± 4.3%  | 11.0% [6.3%]   | 4.5% - 22.3% |
| Total                    | 11.8% ± 3.7%  | 11.4% [5.3%]   | 4.5% - 22.3% |
| **Counts Per Minute**    |               |                |              |
| Males                    | 2330.0 ± 333.7| 2287.8 [359.9] | 1861.1 - 3023.1|
| Females                  | 2498.4 ± 480.3| 2430.4 [744.6] | 1698.7 - 3637.1|
| Total                    | 2445.7 ± 441.4| 2348.2 [648.4] | 1698.7 - 3637.1|
| **Steps Per Minute**     |               |                |              |
| Males                    | 13.4 ± 1.8    | 13.3 [2.7]     | 11.2 - 17.2  |
| Females                  | 13.5 ± 2.3    | 13.8 [3.4]     | 9.0 - 18.6   |
| Total                    | 13.5 ± 2.2    | 13.6 [2.9]     | 9.0 - 18.6   |