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Contact or Collision Sport History, Repetitive Neurotrauma, and Patient-Reported Outcomes in Early to Midadulthood

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Context: Data on the early to midlife effects of repetitive neurotrauma on patient-reported outcomes have been delimited to homogeneous samples of male athletes without comparison groups or accounting for modifying factors such as physical activity.

Objective: To determine the effect of contact or collision sport participation and repetitive neurotrauma on patient-reported outcomes among early to middle-aged adults.

Design: Cross-sectional study.

Setting: Research laboratory.

Patients or Other Participants: A total of 113 adults (53 [46.9%] men, 60 [53.1%] women; age = 34.88 ± 11.80 years) in 4 groups: (1) physically inactive individuals with no repetitive head impact (RHI) exposure (NON); (2) noncontact sport athletes and nonathletes with no RHI exposure who were currently physically active (NCA); (3) former high-risk sport athletes with an RHI history who were physically active (HRS); and (4) former rugby players with prolonged RHI exposure who remained physically active.

Main Outcome Measure(s): The 12-Item Short-Form Health Survey (SF-12), Apathy Evaluation Scale–self-rated version (AES-S), Satisfaction With Life Scale (SWLS), and Sport Concussion Assessment Tool–5th Edition (SCAT5) Symptom and Symptom Severity Checklist.

Results: The NON group had worse self-rated physical function than the NCA group as assessed by the SF-12 physical component summary ($P = .03$) and worse self-rated apathy (AES-S) and satisfaction with life (SWLS) than the NCA ($P = .03$ for both) and HRS groups ($P = .03$ and $P = .040$, respectively). We observed no group differences for self-rated mental health (SF-12 mental component summary; $P = .26$) or symptoms (SCAT5; $P = .42$). Career duration was not associated with any patient-reported outcomes.

Conclusions: A history of contact or collision sport participation and career duration did not negatively affect patient-reported outcomes in physically active, early to middle-aged adults. However, physical inactivity status was negatively associated with patient-reported outcomes in these individuals in the absence of an RHI history.

Key Words: rugby, exercise, mental health, subconcussive impacts

Key Points

- The midlife and later-life effects of repetitive head impacts paired with physical activity on patient-reported outcomes need to be elucidated.
- Contact or collision sport participation and career duration were unrelated to worse patient-reported outcomes in early to midadulthood among physically active individuals.
- Physical inactivity may be a more important modifier of patient-reported outcomes in early to midadulthood than repetitive neurotrauma exposure.

Contact or collision sport participation has been associated with increased prevalence of anxiety, depression, health dysfunction (eg, adverse nutrition and alcohol behaviors), and neuropsychiatric dysfunction in later life,[1] but the data remain mixed.[2,3] The relationship between repetitive head impacts (RHIs), exercise, and long-term health needs to be expanded for us to better understand if the risks of RHI exposure are balanced by the benefits of physical activity through sport or if inactivity without RHI exposure is better for long-term neurologic and mental health (eg, patient-reported outcomes). Indeed, former contact or collision sport participation may yield improved physical health outcomes in later life, possibly due to the chronicity of lifetime physical activity.[4,5] However, this may not translate into improved long-term cognitive and patient-reported outcomes despite the strong link between physical activity and brain health.[6,7] For instance, retired elite rugby players have reported worse mental health outcomes than age-matched amateur rugby players and noncontact athletes[8] in addition to greater prevalences of anxiety, depression, and other mental health conditions.[9]

Limitations of the previous research related to the long-term outcomes of RHIs include generalizability and quantification of RHI exposure, restriction to male populations, and lack of measurement of years of sport participation or physical activity levels.[9–11] Mixed findings exist on the relationship between years of contact or collision sport participation and adverse patient-reported outcomes in young adults.[12,13] Therefore, the effects of collision or contact sport career duration on long-term mental health outcomes beyond early adulthood need to be determined. Several metrics, such as the age of first exposure to contact or collision sport, have been proposed to quantify the RHI burden, but the recent National Institute of Neurological Disorders and Stroke consensus statement[14] on traumatic encephalopathy syndrome recommends career duration as the primary metric. Thus, the relationship between collision sport participation and early to midadulthood on patient-reported outcomes across lifespan, sex, and sporting group needs to be investigated.

Physical activity is a critical component of middle-age and later-life health, with team sport participation also positively influencing patient-reported outcomes across multiple domains.[15] Conversely, sedentary behavior is linked to poorer patient-reported outcomes[16] and is a modifiable risk factor for neurodegenerative disease.[17] As such, comparison groups are needed to further separate the potential neuroprotective effects of exercise and the negative effects of RHI on neurodegeneration and patient-reported outcomes. Hence, the effects of RHI on patient-reported outcomes across the sporting and physical activity level spectrum (ie, athletes without RHI exposure, contact or collision sport athletes, and physically inactive individuals) need to be identified.

Studies of rugby players can provide insight on the mixed relationship between contact or collision sport participation and long-term patient-reported outcomes.[3,13,18] Rugby provides exclusive insight into the effects of RHIs on mental health in midadulthood for both sexes, as it is the only Olympic team collision sport played by female athletes in which the laws, rules, and equipment are the same across sexes.[13,19] Furthermore, most rugby players have prolonged careers as amateur athletes into adulthood and beyond college.[13] However, despite lengthy careers among community rugby cohorts, career duration was unrelated to patient-reported outcomes in early to middle-aged adults.[13] Most previous investigations of the relationship between RHIs in adulthood and patient-reported outcomes have primarily involved male football or soccer players.[18,20,21] Therefore, the primary purpose of our study was to determine the relationship between RHI exposure from contact or collision sport participation on patient-reported outcomes in early to midadulthood among individuals with various levels of RHI exposure and self-reported physical activity. We hypothesized that individuals with a history of prolonged RHI exposure and those who were physically inactive would have worse patient-reported outcomes than individuals who were active with little or no RHI exposure history. The secondary purpose of our work was to assess the relationship between years of exposure to contact or collision sport and patient-reported outcomes in early to middle-aged adults. We hypothesized that longer career duration would be associated with worse patient-reported outcomes.

METHODS

Participants

Participants were recruited via word of mouth, local sport and recreation groups, email, and printed flyers. We recruited a total of 113 adults (53 [46.9%] men, 60 [53.1%] women; age = 34.88 ± 11.80 years), representing 4 distinct groups with various RHI histories and physical activity status and described elsewhere (Table 1).[22] The 4 groups represented physically inactive (NON) and active (NCA) individuals with no RHI exposure through contact or collision sports and physically active individuals with either previous RHI exposure through contact or collision sports (HRS) or prolonged RHI exposure through rugby participation beyond college (RUG). In addition, the groups self-reported as *physically active* (*yes* or *no*) based on the definition in the American College of Sports Medicine[23] physical activity guidelines (150 min/wk of moderate or 60 min/wk of vigorous physical activity). Briefly, the NON (non-RHI exposed, inactive) group represented physically inactive individuals without a history of playing contact or collision sports. The NCA (non-RHI exposed, physically active) group represented physically active individuals without a history of contact or collision sport participation. The HRS (RHI exposed through high-risk sports, physically active) group represented physically active individuals who previously participated in contact or collision sports with RHI exposure, but ceased participation at age 22 years. Lastly, the RUG (prolonged RHI exposure through rugby, physically active) group represented physically active individuals who reported participating in rugby beyond college but had since ceased participation. Volunteers were excluded if they self-reported current pregnancy; a concussion within 6 months of enrollment; a history of stroke or neurodegenerative disease; or any preexisting neurologic, balance, hearing, vestibular, or ocular disorder. All participants provided oral and written informed consent in accordance with the Institutional Review Board of the University of Delaware, which approved the study.

Procedures

Participants completed online questionnaires (Qualtrics) consisting of relevant descriptive variables, physical activity status (*yes* or *no* according to the American College of Sports Medicine[23] guidelines), sport history, and contact or collision sport career duration (sum of all years played of each contact or collision sport). They also completed various measures of mental health and patient-reported outcomes via Qualtrics. We chose these patient-reported outcomes because they have been well used in the concussion and RHI literature, and some have shown group differences in later life among rugby and football players.[5,18,21,24]

Table 1. Participant Characteristics by Group and Group Descriptions

Group	Contact Sport History	Physically Active	Age, y, Mean ± SD (Range; 95% CI)	Sex, Female, No. (%)	Concussion History, Yes, No. (%)	Contact or Collision Sport Career Duration, y	Education Level, No. (%)			
							High School	Some College	Undergraduate Degree	Graduate Degree
No exposure to repetitive head impacts, inactive (n = 28)	No	No	35.43 ± 14.17 (18–67; 29.93, 40.92)	19 (67.9)	7 (25.0)	NA	0 (0.0)	1 (14.3)	15 (53.6)	9 (32.1)
No exposure to repetitive head impacts, physically active (n = 29)	No	Yes	33.90 ± 10.79 (23–67; 29.87, 37.93)	19 (65.5)	11 (37.9)[a,b]	NA	2 (6.9)	0 (0.0)	10 (34.5)	17 (58.6)
Exposure to repetitive head impact through high-risk sports, physically active (n = 29)	Yes	Yes	33.29 ± 8.39 (22–58; 29.03, 35.54)	11 (37.9)	17 (58.6)[c]	14.48 ± 9.30	2 (6.9)	0 (0.0)	10 (34.5)	17 (58.6)
Prolonged exposure to repetitive head impacts through rugby, physically active (n = 27)	Prolonged beyond age 22 y	Yes	38.07 ± 12.98 (22–67; 32.94, 43.21)	11 (40.7)	19 (70.4)[c]	16.33 ± 11.98	0 (0.0)	1 (3.7)	15 (55.6)	11 (40.7)
Overall (n = 113)	NA	NA	34.88 ± 11.80 (18–67; 32.68, 37.07)	60 (53.1)	55 (48.7)	15.37 ± 10.62	NA	NA	NA	NA
P Value	NA	NA	.32	.09	.005	.002	.808			
Effect size, η^2	NA	NA	0.032	0.059	0.110	0.131	0.010			

Abbreviation: NA, not applicable.

[a] Indicates a difference from the exposure to repetitive head impact through high-risk sports, physically active group.

[b] Indicates a difference from the prolonged exposure to repetitive head impacts through rugby, physically active group.

[c] Indicates a difference from the no exposure to repetitive head impacts group.

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Patient-Reported Outcomes

12-Item Short-Form Health Survey. The 12-Item Short-Form Health Survey (SF-12) consists of 12 questions related to one's functional health and well-being. Scores are grouped into SF-12 Physical Component Summary (PCS) and Mental Component Summary (MCS) subscales reflecting perceived physical and mental health, respectively.[25] Scores range from 0 to 100, with higher scores indicating better quality of life and a score of 50 ± 10 representing the average American.[25]

Apathy Evaluation Scale–Self-Rated Version. The Apathy Evaluation Scale–self-rated version (AES-S) consists of 18 questions on self-reported apathy in the last 4 weeks.[26] Scores range from 18 to 72, with higher scores indicating worse apathy and scores ≥34 signifying clinically meaningful apathy.[26]

Satisfaction With Life Scale. The Satisfaction With Life Scale (SWLS) is a 5-statement questionnaire in which individuals rate life satisfaction from 1 (*strongly disagree*) to 7 (*strongly agree*).[27] Scores range from 5 (*lowest*) to 35 (*highest satisfaction with life*), with a score <20 considered *dissatisfaction with one's life*.[27]

Sport Concussion Assessment Tool–5th Edition Symptom and Symptom Severity Checklist. The Sport Concussion Assessment Tool–5th Edition (SCAT5) Symptom and Symptom Severity Checklist is a 22-item checklist in which individuals rate their symptoms based on how they typically feel on a scale from 0 (*none*) to 6 (*severe*).[28] Symptoms are reported as the total number of symptoms, with a rating ≥1 indicating the presence of that symptom, for a total symptom count ranging from 0 (*none*) to 22 (*every symptom present*). Symptom severity is the summed ratings of each symptom, with a possible symptom severity burden ranging from 0 to 132; a larger number indicates a greater symptom burden and greater severity.[28]

Statistical Analysis

We used either a 1-way analysis of variance to compare the 4 groups or a Mann-Whitney *U* test to compare the contact or collision groups on all descriptive data (Table 1). Data were tested for normality using the Shapiro-Wilk statistic and violated the assumption of normality (Shapiro-Wilk value < .05). To test our hypotheses, we first compared groups in an unadjusted model (model 1) across all patient-reported outcomes (ie, SF-12 PCS and MCS, AES-S, SWLS, SCAT5 symptom count and symptom severity) using a 1-way analysis of variance. For outcomes that were different, we performed a pairwise comparison procedure and Bonferroni correction for multiple comparisons. We used χ^2 analysis to compare the proportions of participants in each group meeting the clinical cutoff scores for the SF-12 PCS and MCS, AES-S, and SWLS. Outcomes were followed up with a post hoc z test of the adjusted residuals with the Bonferroni correction to determine which groups differed from each other.

To control for potential contributors to model 1, we compared the groups in model 2 using an analysis of covariance, adjusting for the known covariates of age, sex, and concussion history that may affect patient-reported outcomes.[8,10,29] For outcomes that were different, we performed a post hoc analysis using the Bonferroni test for multiple comparisons. Effect sizes for each test are reported as η^2 for unadjusted models or partial η^2 for adjusted models and interpreted as *small* (0.01), *medium* (0.06), or *large* (0.14).[30]

To investigate the relationship between career duration and patient-reported outcomes, we conducted a linear regression using the enter method to determine the association between all patient-reported outcomes in collision sport athletes (ie, HRS and RUG groups) and contact or collision sport career duration (years). For follow-up analyses, we used a multiple linear regression to evaluate the association between patient-reported outcomes and career duration and known covariates: age (years), sex, and concussion history. The test assumptions of independence of observations, linearity, homoscedasticity, multicollinearity, and normal distribution of the residuals were all confirmed. The α level was set at .05, and all analyses were performed using SPSS (version 28; IBM Corp).

RESULTS

Mean, SD, range, and 95% CI for each physical and mental health patient-reported outcome (ie, SF-12 PCS and MCS, AES-S, SWLS, SCAT5 symptom count and symptom severity) are presented in Table 2.

Patient-Reported Outcomes

Model 1 (Unadjusted). In the unadjusted model, we found a difference between groups for the SF-12 PCS ($F_{3,106} = 4.143$, $P = .008$) with a post hoc difference identified between NCA and RUG (adjusted $P = .01$) and NCA and NON (adjusted $P = .04$), whereby the SF-12 PCS was higher (ie, better) in the NCA group than in both the NON and RUG groups (Figure 1A). We observed no group differences for the SF-12 MCS ($F_{3,106} = 0.702$, $P = .55$; Figure 1B), total symptom count ($F_{3,106} = 0.824$, $P = .48$), or symptom severity ($F_{3,106} = 0.974$, $P = .41$; Table 3).

A difference existed in the unadjusted model between groups for the AES-S ($F_{3,106} = 3.601$, $P = .02$), but no post hoc differences were evident ($P > .05$; Figure 1C; Table 3). Lastly, we noted a difference between groups for the SWLS ($F_{3,106} = 4.161$, $P = .008$), with post hoc differences between HRS and NON (adjusted $P = .03$) and NCA and NON (adjusted $P = .03$), such that the NON group had a lower (ie, worse) SWLS outcome than the NCA and HRS groups (Figure 1D). These results are presented with the abnormal scores shaded in grey in Figure 1A–D.

Model 2 (Adjusted). After adjustments for age, sex, and concussion history, a slightly attenuated main effect of group for the SF-12 PCS with a medium effect size ($F_{3,106} = 3.530$, $P = .02$; $\eta^2 = 0.091$) was found with post hoc differences between the NCA and NON ($P = .03$), whereby the NON group had lower (ie, worse) self-rated physical function (Table 3). Only group was a contributor to the model ($P = .02$); age ($P = .09$), sex ($P = .47$), and concussion history ($P = .13$) were not. We demonstrated no group differences for the SF-12 MCS ($F_{3,106} = 1.349$, $P = .26$).

A group difference ($F_{3,106} = 4.230$, $P = .007$) with medium effect size ($\eta^2 = 0.107$) was seen for the AES-S with post hoc differences characterized, such that the NON group had a higher (ie, worse) score than the NCA ($P =$ .03) and HRS ($P = .040$) groups. Both sex ($P = .01$) and group ($P = .007$) were contributors to the AES-S adjusted model. Further group differences were observed for the

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Table 2. Patient-Reported Outcomes by Group

Outcome	Group				Overall (N = 113)
	No Exposure to Repetitive Head Impacts, Inactive (n = 28)	No Exposure to Repetitive Head Impacts, Physically Active (n = 29)	Exposure to Repetitive Head Impacts Through High-Risk Sports, Physically Active (n = 29)	Prolonged Exposure to Repetitive Head Impacts Through Rugby, Physically Active (n = 27)	
12-Item Short-Form Health Survey Physical Component Summary, mean ± SD (range; 95% CI)	53.23 ± 6.16 (33.8–61.4; 50.84, 55.62)	56.69 ± 2.22[a] (52.28–65.03; 55.84, 57.53)	55.05 ± 2.91 (46.8–60.4; 53.95, 56.16)	52.80 ± 6.12[b] (30.7–57.5; 53.95, 56.16)	54.48 ± 4.86 (30.7–65.0)
Abnormal (<50), No. (%)	5 (17.9)	0 (0)	1 (3.4)	4 (14.8)	NA
12-Item Short-Form Health Survey Mental Component Summary, mean ± SD (range; 95% CI)	51.00 ± 8.27 (32.7–61.3; 47.79, 54.21)	51.82 ± 7.25 (29.70–58.08; 49.06, 54.58)	52.32 ± 6.21 (36.3–60.8; 49.95, 54.67)	49.36 ± 10.42 (22.6–60.3; 45.24, 53.48)	51.16 ± 8.11 (22.6–61.3)
Abnormal (<50), No. (%)	10 (35.7)	8 (27.6)	8 (27.6)	10 (37.0)	NA
Apathy Evaluation Scale-Self Rated, mean ± SD (range; 95% CI)	28.54 ± 5.75[b] (19–41; 26.31, 30.77)	24.34 ± 4.22[c] (18–34; 22.74, 25.95)	24.93 ± 5.54 (18–37; 22.83, 27.04)	28.00 ± 7.85 (19–56; 24.89, 31.11)	26.41 ± 6.15 (18–56)
Abnormal (≥34), No. (%)	5 (17.9)	1 (3.4)	4 (13.8)	4 (14.8)	
Satisfaction With Life Scale, mean ± SD (range; 95% CI)	25.18 ± 5.88[b,d] (9–35; 22.90, 27.46)	29.24 ± 4.93[c] (16–35; 27.37, 31.12)	29.21 ± 3.77[c] (20–35; 27.77, 30.64)	26.44 ± 6.41 (12–35; 23.91, 28.98)	27.56 ± 5.54 (9–35)
Abnormal (<20), No. (%)	4 (14.3)	1 (3.4)	0 (0)	5 (18.5)	NA
Total symptoms, mean ± SD (range)	5.00 ± 4.32 (0.00–17.00)	4.07 ± 3.66 (0.00–13.00)	5.24 ± 5.52 (0.00–21.00)	6.15 ± 6.11 (0.00–21.00)	5.10 ± 4.98 (0.00–21.00)
Symptom severity, mean ± SD (range)	8.64 ± 9.23 (0.00–41.00)	6.07 ± 6.70 (0.00–28.00)	10.45 ± 19.33 (0.00–103.00)	11.56 ± 12.65 (0.00–49.00)	9.14 ± 12.91 (0.00–103.00)

[a] Indicates a difference from the prolonged exposure to repetitive head impacts through rugby, physically active group.
[b] Indicates a difference from the no exposure to repetitive head impacts, physically active group.
[c] Indicates a difference from the no exposure to repetive head impacts, inactive group.
[d] Indicates a difference from the exposure to repetitive head impacts through high-risk sports, physically active group.

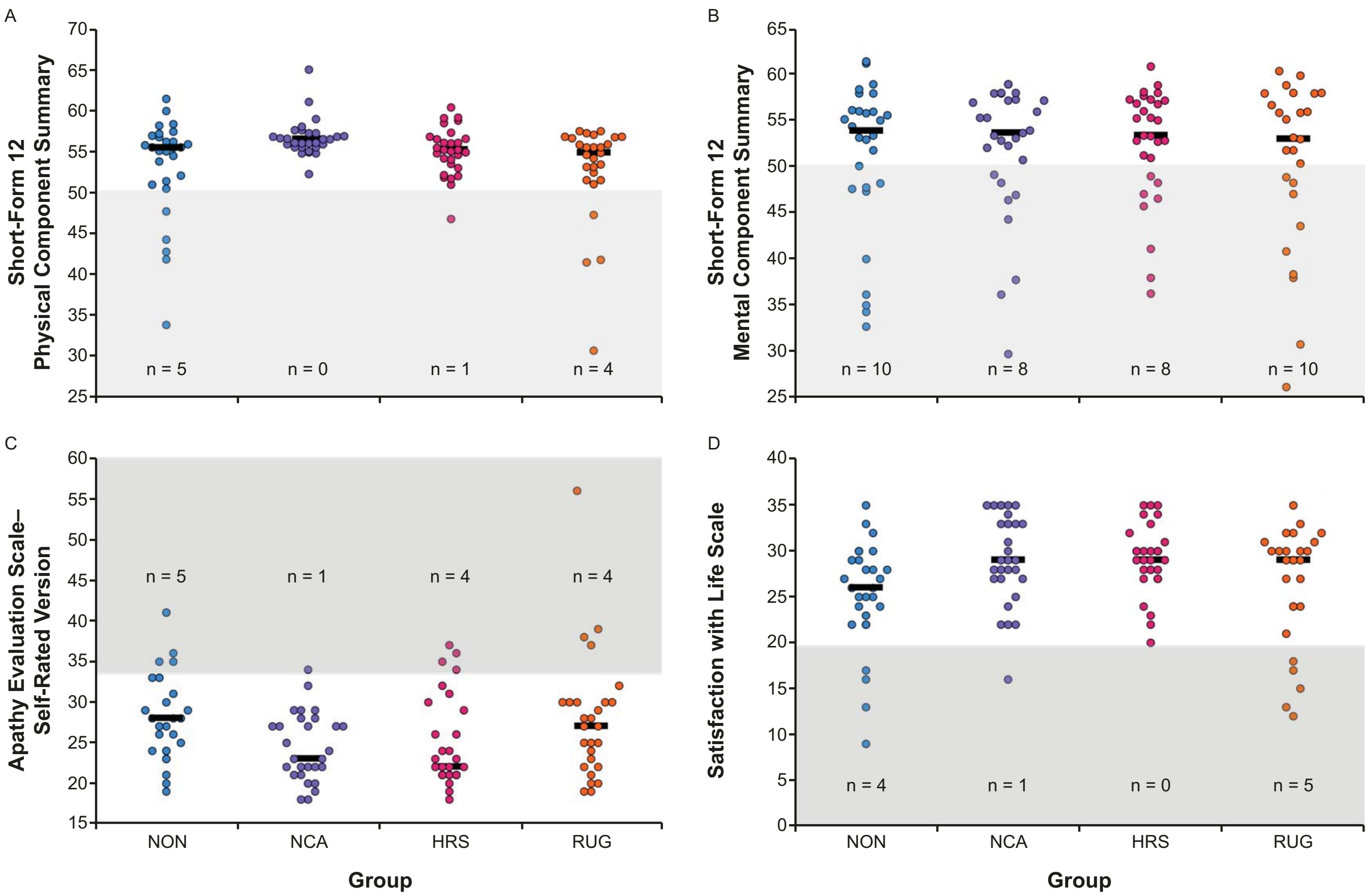

Figure 1. Patient-reported outcomes by group with abnormal scores highlighted in gray. A, 12-Item Short-Form Health Survey Physical Component Summary. B, 12-Item Short-Form Health Survey Mental Component Summary. C, Apathy Evaluation Scale-Self Reported. D, Satisfaction With Life Scale. Abbreviations: HRS, exposure to repetitive head impacts through high-risk sports, physically active (n = 29); NCA, no exposure to repetitive head impacts, physically active (n = 29); NON, no exposure to repetitive head impacts, inactive (n = 28); RUG, prolonged exposure to repetitive head impacts through rugby, physically active (n = 27).

SWLS ($F_{3,106} = 4.354$, $P = .006$) with a medium effect size ($\eta^2 = 0.110$), whereby the NON group had a lower (ie, worse) SWLS score than the NCA ($P = .03$) and HRS ($P = .03$) groups; only group was a contributor to the adjusted model ($P = .006$). Lastly, no group differences occurred for symptom count ($F_{3,106} = 0.953$, $P = .42$) and symptom severity ($F_{3,106} = 0.851$, $P = .47$).

Career Duration and Patient-Reported Outcomes

Unadjusted Models. None of the models were associated with any of the patient-reported outcomes ($P > .05$; Table 4; Figure 2A–F).

Adjusted Models. The multiple regression model was different for the SF-12 PCS ($F_{4,51} = 3.899$, $P = .008$, adjusted $R^2 = 0.174$), indicating a medium effect size.[30] The predictor variables (age, sex, career duration, and concussion history) explained 20.9% of the variability in the SF-12 PCS. However, only age added to the model ($P = .004$): every 1-year increase in age was associated with a 0.138 decrease in the SF-12 PCS score (Table 4).

None of the other models were different for any of the patient-reported outcomes ($P > .05$). Nonetheless, age added to the SF-12 MCS model ($P = .04$), whereby every 1-year increase in age was associated with a 0.242 increase in the SF-12 MCS score.

Proportion of Abnormal Scores by Group

The percentages of abnormal responses (ie, meeting the standard of a clinical cut point cited in the earlier test descriptions) are also highlighted (Table 2). The χ^2 findings are reported in Table 5. A post hoc z test of the adjusted residuals revealed that the proportion of individuals in the NON group with abnormal (ie, low) SF-12 PCS scores was greater than that in the NCA group. In addition, the proportion of participants with abnormal SWLS scores (ie, dissatisfaction with life) in the RUG group was different from that in the other 3 groups, such that a greater proportion of participants in the RUG group self-reported dissatisfaction with life.

DISCUSSION

Contrary to our hypothesis, RHI exposure history was unrelated to patient-reported outcomes in early to midadulthood among individuals who were physically active. However, supporting our hypothesis, individuals who were not physically active had worse patient-reported outcomes (ie, worse SF-12 PCS, AES-S, and SWLS scores). Second, counter to our hypothesis, the duration of the contact or collision sport career was unrelated to adverse patient-reported outcomes in early to midadulthood among current

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Table 3. Unadjusted and Adjusted Model Comparisons of Patient-Reported Outcomes by Group

Measure	Model	$F_{3,106}$ Value	*P* Value	Partial η^2	Post Hoc Difference	
					Comparison	*P* Value
12-Item Short-Form Health Survey Physical Component Score	Model 1 (unadjusted)	4.143	.008[a]	0.102	NCA > RUG	.01
					NCA > NON	.04
	Model 2 (adjusted)	3.530	.02[a]	0.091	NCA > NON	.03
12-Item Short-Form Health Survey Mental Component Score	Model 1 (unadjusted)	0.702	.55	0.019	NA	NA
	Model 2 (adjusted)	1.349	.26	0.037	NA	NA
Apathy Evaluation Scale-Self Rated	Model 1 (unadjusted)	3.601	.02[a]	0.090	NA	NA
	Model 2 (adjusted)	4.230	.007[a]	0.107	NON > NCA	.03
					NON > HRS	.040
Satisfaction With Life Scale	Model 1 (unadjusted)	4.161	.008[a]	0.103	HRS > NON	.03
					NCA > NON	.03
	Model 2 (adjusted)	4.354	.006[a]	0.110	NCA > NON	.03
					HRS > NON	.03
Symptom count	Model 1 (unadjusted)	0.824	.48	0.022	NA	NA
	Model 2 (adjusted)	0.953	.42	0.026	NA	NA
Symptom severity	Model 1 (unadjusted)	0.974	.41	0.026	NA	NA
	Model 2 (adjusted)	0.851	.47	0.024	NA	NA

Abbreviations: HRS, exposure to repetitive head impacts through high-risk sports, physically active; NA, not applicable; NCA, no exposure to repetitive head impacts, physically active; NON, no exposure to repetitive head impacts, inactive; RUG, prolonged exposure to repetitive head impacts through rugby, physically active.

[a] Indicates a difference at the .05 level with adjustment for multiple comparisons.

and former contact or collision sport athletes, as evidenced by the lack of contribution to the models. Overall, these findings suggest that RHI exposure, whether previous or prolonged, may not negatively affect patient-reported outcomes among physically active individuals in early to midadulthood; still, the effects in later life remain to be elucidated.

Previous studies[14,18] on postcollege-aged individuals have been limited to primarily young or older male cohorts and have not accounted for current physical activity, a modifiable risk factor for numerous health conditions. Our results suggested that patient-reported outcomes were not worse among early to middle-aged adults with a history of sport-related RHI exposure who reported being physically active than among both physically active and inactive individuals without a history of sport-related RHI exposure. This finding is consistent with research on former National Collegiate Athletic Association Division III athletes in midlife, which indicated that collision sport athletes did not have worse neurobehavioral quality-of-life outcomes but that a concussion history was associated with worse quality of life.[3] Indeed, the benefits of exercise and physical activity on mood, anxiety and depression, dementia, cardiovascular disease, metabolic syndrome, and other noncommunicable diseases are well established.[6] Therefore, the reason that neither RHI-exposed group (HRS and RUG) displayed worse scores on any outcome than the NCA group may be due to the neuroprotective and beneficial effects of exercise and regular physical activity and to the fact that these participants were in their mid-30s. In addition, given that the NON group's self-reported scores were worse than those of the NCA group for 3 patient-reported outcomes (ie, SF-12 PCS, AES-S, and SWLS) despite never having experienced RHI through contact or collision sport further highlights the detrimental effects of a lack of physical activity and presumably low levels of cardiorespiratory fitness, which have been major risk factors linked with many diseases and health conditions (eg, cardiometabolic disease, all-cause deaths, systemic inflammation, stress, anxiety, Alzheimer disease).[6]

Despite many group differences in the adjusted models, a considerable proportion of participants in each group had scores outside the clinical cut points (Tables 2 and 3; Figure 1). For instance, the NON group self-reported lower SF-12 PCS scores in the adjusted models than the NCA group. As evidenced in Tables 2 and 3, a greater proportion of individuals in the NON group (17.9%) had SF-12 PCS scores below the

Table 4. Multiple Linear Regression: Collision Sport Athletes and Patient-Reported Outcomes[a]

Outcome	Model Values							
	Unadjusted				Adjusted[b]			
	$F_{4,51}$	*P*	R^2	Adjusted R^2	$F_{4,51}$	*P*	R^2	Adjusted R^2
12-Item Short-Form Health Survey Physical Component Score	0.636	.43	0.012	−0.007	3.899	.008[c]	0.231	0.174
12-Item Short-Form Health Survey Mental Component Score	1.423	.24	0.026	0.008	1.897	.13	0.130	0.061
Apathy Evaluation Scale-Self Rated	0.058	.81	0.001	−0.017	1.407	.25	0.099	0.029
Satisfaction With Life Scale	1.946	.17	0.035	0.017	1.101	.37	0.079	0.007
Symptom count	2.055	.16	0.037	0.019	1.091	.37	0.080	0.007
Symptom severity	1.142	.29	0.021	0.003	1.081	.38	0.080	0.006

[a] Career duration was the predictor variable for all models.
[b] Adjusted model covariates were age, sex, career duration, and concussion history.
[c] Indicates a difference ($P < .05$).

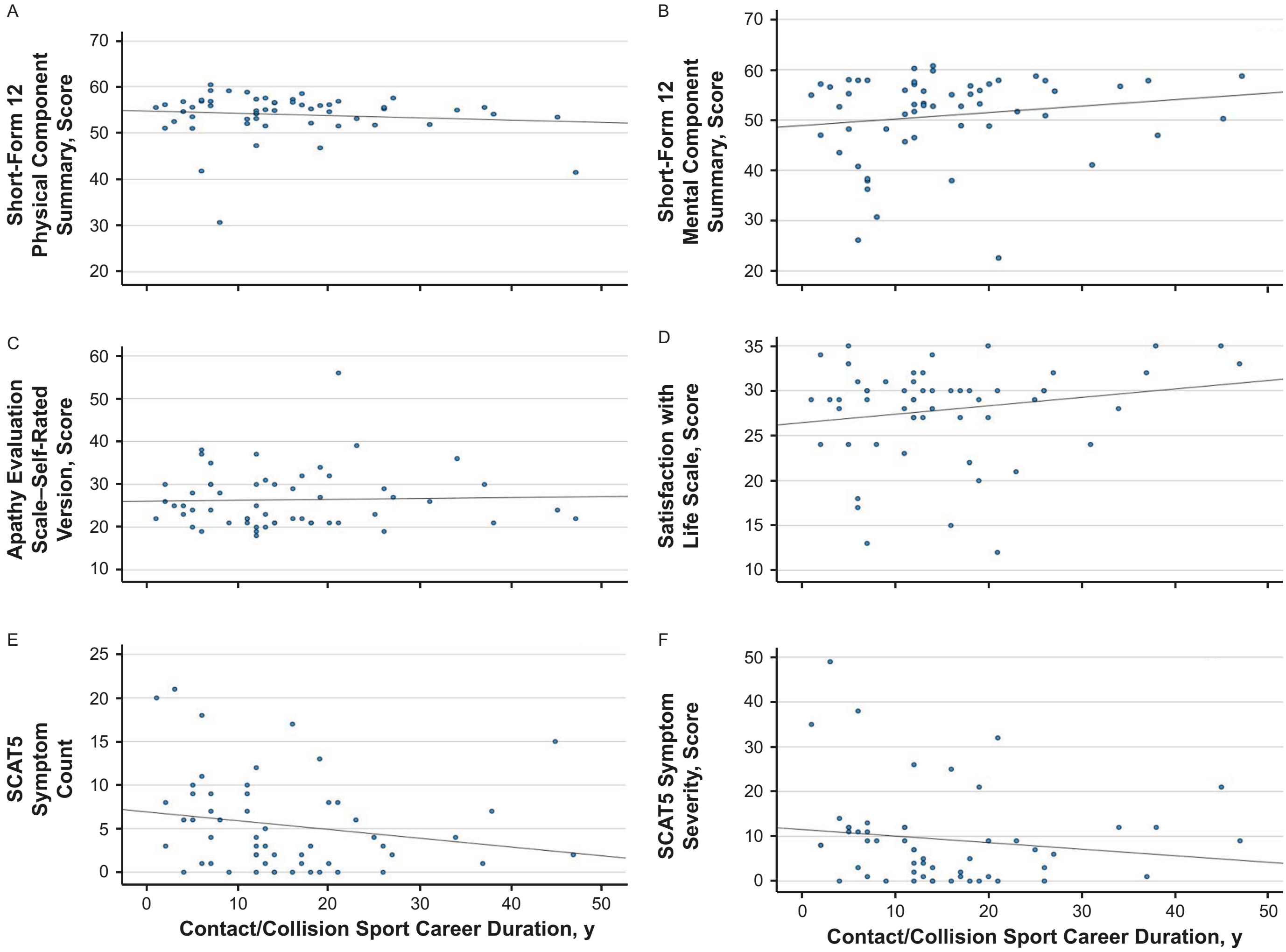

Figure 2. Career duration and patient-reported outcome regressions. Unadjusted regression graphs for career duration (years) versus A, 12-Item Short-Form Health Survey Physical Component Summary, B, 12-Item Short-Form Health Survey Mental Component Summary, C, Apathy Evaluation Scale-Self Reported, D, Satisfaction With Life Scale, E, Sport Concussion Assessment Tool–5th Edition (SCAT5) symptom count, and F, SCAT5 symptom severity. None of the models were different (*P* values > .05).

population average of 50 compared with the NCA group (0%). The χ^2 analysis, however, only revealed a difference in the proportion of individuals with low SF-12 PCS scores in the NON group compared with the NCA group. Moreover, a greater proportion of participants in the RUG group (18.5%) expressed dissatisfaction with life as shown in SWLS scores <20 of 35 than the NON (14.3%), NCA (3.4%) and HRS (0%) groups, which may have been related to longer career durations in RHI sports.[27] Herein lies a unique trend: although most of our group differences reflected worse performance in the NON group than the NCA group in the adjusted models, signifying that former contact or collision sport athletes (ie, HRS and RUG) were not performing worse than physically active individuals who never experienced RHI, we observed a substantial proportion of individuals in the NON, HRS, and RUG groups who displayed clinically meaningful dysfunction (up to 37%). Indeed, RHI exposure confers risk, but for most of these athletes, the benefits appeared to outweigh the negative risks related to patient-reported outcomes. Yet a subpopulation of athletes in whom the risk-to-benefit ratio inclines toward a

Table 5. Chi-Square Tests for Proportions of Clinical Cutoffs Scores by Group

Measure	χ^2	*P* Value	Post Hoc Difference
12-Item Short-Form Health Survey			
Physical Component Summary	7.8719	.049[a]	NON > NCA
Mental Component Summary	1.0129	.80	NA
Apathy Evaluation Scale-Self Rated	3.1060	.38	NA
Satisfaction With Life Scale	8.0194	.046[a]	RUG > NCA, NON, HRS

Abbreviations: HRS, exposure to repetitive head impacts through high-risk sports, physically active; NA, not applicable; NCA, no exposure to repetitive head impacts, physically active; NON, no exposure to repetitive head impacts, inactive; RUG, prolonged exposure to repetitive head impacts through rugby, physically active.

[a] Indicates a difference ($P < .05$).

greater risk of dysfunction may exist. Although the progression of this dysfunction cannot be determined from these data, it highlights a clear trend that some individuals in these cohorts performed worse than their peers, which warrants investigation to measure their later-life patient-reported outcomes.

Counter to our secondary hypothesis, the duration of the contact or collision sport career was unrelated to patient-reported outcomes among former contact or collision sport athletes (HRS and RUG). Our study expanded on previous research in which authors assessed career duration and patient-reported outcomes in rugby players[13] by including physical activity status and other collision sport athletes. Indeed, a variety of contact or collision sports have been linked to adverse mental health, a heightened prevalence of anxiety and depression compared with the general population, and worse quality of life than in low- or noncontact athletes.[5,8,9] Moreover, contact or collision sport participation has been associated with a variety of neurologic and neurodegenerative diseases.[4,20] However, conflicting information has suggested that contact or collision sport participation is unrelated to worse mental and psychological health outcomes in middle life[13,18,31] and unrelated to neurologic disease diagnoses in American football players.[12] Consistent with a study of community rugby players (approximately 32 years old) who had an average contact or collision sport career length of approximately 13 years, we found that career duration was unrelated to patient-reported outcomes.[13] Herein, our sample of contact or collision sport athletes was relatively the same age (approximately 35 years old) with a similar contact or collision sport career duration (15 years), but importantly, both samples consisted of approximately 41% women, as female athletes have been historically underrepresented in traumatic brain injury–related research.[32] As such, career duration may be unrelated to patient-reported outcomes across sexes in early to midadulthood but should remain a variable of interest due to its relationship with later-life neurodegenerative disease.[20]

The primary limitation of our work was that the groups were not matched by age and sex. Nonetheless, the groups did not differ in the age or sex breakdown. Moreover, the inclusion of a large proportion of women was a relative strength because female athletes have been underrepresented in the previous literature.[32] Another limitation was the use of career duration as a metric for RHI exposure. Despite its identification by the National Institute of Neurological Disorders and Stroke consensus statement on traumatic encephalopathy syndrome[14] as the only modifiable risk factor, RHI exposure does not account for the sport, position, level of play, or volume of play over a lifetime. Our study was limited in its design, which prevented us from delineating the effects of physical activity and RHI on patient-reported outcomes. Future investigators should use more sensitive measures of physical activity to determine the chronicity of lifetime physical activity to further elucidate the potential protective effects of exercise on the relationship between repetitive neurotrauma and patient-reported outcomes in early to midadulthood. Lastly, our sample may have been susceptible to respondent and survivor bias, whereby collision sport athletes who had physical and mental dysfunction may have ceased participation in sport, not volunteered for our study, or both, whereas healthy, more resilient athletes continued to participate and subsequently volunteered.

Neither a history of contact or collision sport participation nor the duration of the contact or collision sport career negatively affected patient-reported outcomes among physically active individuals in early to midadulthood. However, a sedentary lifestyle was negatively associated with patient-reported outcomes in the absence of RHI exposure. Importantly, a nontrivial proportion of participants across groups had abnormal patient-reported outcomes, suggesting a potential threshold between RHI exposure risk and the benefits of sport and exercise. These findings fill critical gaps in the literature and add to the growing body of research,[12,13,18] suggesting that career duration is unrelated to psychological health dysfunction in early to midadulthood. Future authors should expand on these results by evaluating older cohorts and using more precise measures of physical activity status and history as well as RHI exposure history to better understand the risk-to-benefit ratio between RHI exposure and physical activity throughout the lifespan.

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