



sport athletes to the exclusion of females and other sport/cohort groups.<sup>3,7</sup>

Rugby is the most popular collision sport worldwide and the only collision sport where the laws are the same for both males and females,<sup>8,9</sup> thus indicating similar RHI exposure.<sup>10</sup> While most contact/collision sport athletes typically stop their careers after high school or college, many Americans only begin playing rugby at this time. Therefore, they continue to experience RHI through adulthood and often exceed the traumatic encephalopathy syndrome threshold for exposure.<sup>7,11,12</sup> Growing evidence links rugby participation and long-term physical and mental health dysfunction; however, sports participation during adulthood is associated with increased physical activity, a known positive modifier of long-term health outcomes.<sup>13–16</sup> Thus, the negative effects of RHI and the positive effects of physical activity on mid- and later-life neurobehavioral health (e.g., gait) remain to be elucidated.<sup>15,17,18</sup>

Previous research on the long-term effects of RHI exposure has relied on self-report or on simplistic clinical measures with little to no inquiry into more objective and sensitive measures of neurobehavioral health in aging/post-collegiate populations.<sup>3,19–22</sup> Gait has been referred to as the 6th vital sign since it is an objective measure of neurological health, reflects quality of life, and is sensitive to age- and neurological impairment-related changes, with decreased performance (i.e., conservative gait strategies) in older and neurologically compromised populations.<sup>23–25</sup> The addition of a cognitive challenge during gait, termed dual-task (DT) gait, has been utilized to identify differences between neurologically impaired populations and healthy controls.<sup>26</sup> Further, DT gait can be used to identify post-concussion and persistent subclinical deficits in executive function as well as neurophysiological impairments by calculating the DT cost (i.e., the change from single task (ST) to DT).<sup>26</sup> Yet, because most investigations into gait abnormalities due to RHI exposure/neurotrauma have been limited to younger (e.g., college or high school) male collision sport athletes or male and female contact/collision sport athletes and have failed to account for potential confounders (e.g., body mass index (BMI), age, concussion history, and sex), the long-term effects of RHI on gait remain inconclusive.<sup>19,20,22</sup>

Contact/collision sport-related RHI have been associated with poorer long-term health outcomes,<sup>7,17</sup> but increased physical activity is known to improve many health outcomes.<sup>15,27</sup> Thus, the purpose of this study was to determine the relationship between contact/collision sport career duration on ST and DT gait in physically active early- to middle-aged adults. We hypothesized that individuals with a history of RHI exposure would have a conservative gait strategy, evidenced by slower gait speed, a longer percentage of time in double support, and shorter stride length compared to individuals without RHI exposure. Secondly, we hypothesized that longer career duration would be associated with a conservative gait strategy (i.e., decreased gait speed and stride length, and increased double support) and worse DT cost in collision sport athletes.

## 2. Methods

### 2.1. Participants

Power analyses have been historically underutilized in neurotrauma and gait research.<sup>28</sup> As such, a power analysis (G\*Power 3.1; <https://link.springer.com/content/pdf/10.3758/BF03193146.pdf>) was conducted based on the ST gait speed of 13 total subjects across the 4 groups. (The ability of ST gait to discriminate healthy from neurologically impaired individuals has been shown in previous research.<sup>29,30</sup>) Results indicated that 22 participants were needed per group to achieve 80% power for a medium effect size (Cohen's  $f=0.25$ );<sup>31</sup> overall, 113 adults were enrolled (Table 1) (Fig. 1). Groups differed significantly in terms of BMI and concussion history, and thus these variables were accounted for in adjusted models. The inclusion and exclusion criteria for the 4 groups (non-athletes (NON), non-contact/collision athletes (NCA), high-risk sport athletes (HRS), and rugby/prolonged RHI exposure athletes (RUG)) are described below (Table 2). Consistent with previous studies, contact/collision sports included those with potential and/or routine RHI exposure (i.e., American football, soccer, ice hockey, boxing, rugby, lacrosse, and wrestling).<sup>2,11</sup> Briefly, participants were recruited from 4 groups: (a) NON: individuals with no previous contact/collision sport experience who are not currently physically active ( $n=28$ ); (b) NCA: non-contact/collision sport athletes/individuals with no previous contact/collision sport experience who are physically active ( $n=29$ ); (c) HRS: former contact/collision sport athletes who are physically active ( $n=29$ ); and (d) RUG: current/former rugby players with a history of playing rugby after age 22 who are physically active ( $n=27$ ). Of note, none of the RUG group participants had actively participated in contact rugby in the 6 months prior to the study due to coronavirus disease 2019 (COVID-19) related shutdowns (years since last participating in contact/collision rugby:  $8.5 \pm 9.8$  years; range: 0.5–36 years). Participants were recruited via word of mouth, social media, and flyers posted at various sports venues, and they were compensated for their participation in the form of an Amazon.com gift card. All participants provided oral and written informed consent in accordance with the University of Delaware's Institutional Review Board.

### 2.2. Procedures

Participants completed online questionnaires to ascertain relevant demographic information, physical activity status (yes/no meeting American College of Sports Medicine guidelines of 150 min/week of moderate or 60 min/week of vigorous physical activity<sup>32</sup>), sport history, and career duration of contact/collision sports via Qualtrics (Qualtrics, Provo, UT, USA). Consistent with traumatic encephalopathy syndrome guidelines, career duration was calculated for each participant as the sum of each year played in each contact/collision sport (e.g., 2 years of ice hockey and 2 years of American football = 4 years career duration).<sup>7</sup>

Participants completed 5 ST walking trials and 5 DT walking trials with a cognitive task (i.e., spelling 5-letter words











