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Moderate-To-Vigorous Physical Activity Independent of Stationary Time Is Associated With Better Functional Outcomes Over Four-Years in Individuals With or at Risk of Knee Osteoarthritis

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ABSTRACT

Introduction: Osteoarthritis is a progressive joint disease that causes pain and disability, impairing physical function. Moderate-to-vigorous physical activity (MVPA) is recommended for knee osteoarthritis, while stationary time, independent of activity, may negatively impact health outcomes. We hypothesised that individuals with the highest MVPA and lowest stationary time would have better long-term function compared to those with the lowest MVPA and highest stationary time, as well as those with high levels of both MVPA and stationary time.

Methods: Data included 442 participants, with an average age of 66-years and 190-females from the Osteoarthritis Initiative who wore accelerometers to assess MVPA and stationary time. Participants were grouped into tertiles of MVPA and stationary time normalised to total accelerometer wear time. The three groups were: highest activity, lowest stationary (HALS), highest activity, highest stationary (HAHS), and lowest activity, highest stationary (LAHS). Gait speed, the 400 m walk test, and five-time repeated chair stand were assessed at baseline and four-year follow-up.

Results: Compared to the LAHS group, the HALS and HAHS groups had better performance in gait speed $p < 0.001$, $d = 0.96$–1.06, 400m walk time $p < 0.001$, $d = 1.21$–1.36, and five-time repeated chair stand $p < 0.001$, $d = 0.54$–0.81 at baseline and four-year follow-up. No differences were found between the HALS and HAHS groups at either timepoint.

Conclusion: Higher levels of MVPA were associated with better lower-limb functional outcomes in individuals with or at risk of knee osteoarthritis. Higher levels of stationary time do not negatively influence functional performance as long as higher numbers of MVPA levels (~30 min/day) are achieved.

1 | Introduction

Osteoarthritis is a progressive joint disease and a leading cause of pain and functional disability worldwide (Bannuru et al. 2019; Dobson et al. 2013; Hawker 2019). Physical activity, and specifically walking more often, is a highlighted clinical practice guideline recommendation for individuals with knee osteoarthritis (Arden et al. 2021; Katz, Arant, and Loeser 2021; Kolasinski et al. 2020). Currently, these guidelines are not specific to knee osteoarthritis; however, the evidence consistently suggests the importance of physical activity for maintaining functional ability (Chmelo et al. 2013; Fernandopulle et al. 2017; White et al. 2017; Zampogna et al. 2020). Despite this recommendation, research has reported that only 13% of males and 8% of females with knee osteoarthritis achieve recommended levels of physical activity (Dunlop et al. 2011), often due to pain or fear of accelerating/worsening the disease (Kanavaki et al. 2017). Strong evidence demonstrates that individuals with knee osteoarthritis who engage in more physical activity have better self-reported and performance-based measures of pain, function, and disability compared with those who are not physically active (Sliepen et al. 2018; Song et al. 2018).

Despite these benefits, a recent systematic review highlights that nearly one-third of individuals with knee osteoarthritis are sedentary for over 8-h daily (Dawson, Beaumont, and Carter 2023). Traditional guidelines have primarily focused on increasing physical activity, but recent research emphasises the need to also address stationary time as a separate risk factor for poor health outcomes (Kehler and Theou 2019; Ross et al. 2020; Studenski et al. 2011). Notably, it remains unclear whether low stationary time is inherently linked to high physical activity or if stationary time and MVPA contribute independently to health outcomes. For instance, an individual might meet physical activity recommendations yet still engage in high levels of stationary time later in the day (Prince et al. 2014), and the impact of postures on physical function is not well understood. Thus, distinguishing the independent effects of stationary time and MVPA on health outcomes could be crucial for refining guidelines that better address the unique needs of individuals with knee osteoarthritis, ultimately enhancing interventions to improve physical function.

Research on physical activity and stationary time in individuals with or at risk of knee osteoarthritis has often been specific to one of these behaviours. Findings consistently show that individuals who engage in more recreational physical activity tend to perform better on functional tests like the six-minute walk test and stair climb test compared to those who are less active (Fernandopulle et al. 2017). Additionally, cross-sectional studies have demonstrated that individuals who spent greater-than 75% of their wake hours in stationary time exhibit slower gait speed and perform worse on the repeated chair stand test (Lee et al. 2015). Furthermore, a recent evidence map using data from the Osteoarthritis Initiative linked habitual physical activity to improved outcomes in the 20-m walk, 400 m walk, and repeated chair stand tests (Budarick and Moyer 2022). Research that integrates physical activity levels and stationary time in this population has mainly targeted mortality and cardiometabolic outcomes (Ekelund et al. 2020), leaving an important gap regarding functional performance outcomes in knee osteoarthritis.

In light of the American College of Rheumatology's call for a nuanced approach to physical activity research—one that accounts for activity duration, intensity, and stationary time for individuals with osteoarthritis (Kolasinski et al. 2020) — this study aimed to address knowledge gaps surrounding the link between physical inactivity and knee osteoarthritis and function (Allen et al. 2021; Sliepen et al. 2018; Song et al. 2018). The purpose of the current study was to test the hypothesis that individuals who engage in the highest levels of MVPA and lowest levels of stationary time will have better longitudinal outcomes over four-years in performance-based measures of function compared to individuals who engage in the lowest amount of MVPA and highest amount of stationary time, as well as compared to those who engage in the highest levels of both MVPA and stationary time.

2 | Methods

2.1 | Participants

Participants for this study were selected from the Osteoarthritis Initiative, a large multicenter, prospective cohort study designed to improve public health by addressing pain and disability related to knee osteoarthritis. The Osteoarthritis Initiative originally included 4796 individuals aged 45–79 years at baseline, either diagnosed with or at risk for knee osteoarthritis, with detailed inclusion criteria published previously (Nevitt, Felson, and Lester 2006). The OAI grouped participants into three cohorts: control (no risk factors or diagnosis of osteoarthritis; $n = 122$), incidence (express risk factors, such as frequent knee symptoms, but no osteoarthritis diagnosis; $n = 3259$), and progression (diagnosed osteoarthritis defined as pain on most days in the past month, and definite osteophyte presence; $n = 1374$). Participants from both the incidence and progression cohorts were included in the current study. An ancillary study at the Osteoarthritis Initiative's 48-month follow-up measured physical activity levels using accelerometers, where participants were instructed to wear the device during waking hours for one week. This ancillary study included individuals with follow-up visits scheduled between August 2008 and July 2010, resulting in 2712 eligible participants, of whom 2127 consented. In total, 1927 participants wore the accelerometer for at least 10-h per day on a minimum of four days (Dunlop et al. 2011). Only individuals who fell into the highest and lowest tertiles of MVPA and stationary time ($n = 779$), and who completed gait speed, 400 m walk and five-time repeated chair stand tests at baseline (V06 timepoint) and four-year follow up (V10 timepoint) were included in the analyses, yielding a total of 442 participants. This study adhered to the ethical guidelines of the Helsinki Declaration, with all participants providing written informed consent, and approval was obtained from the relevant local ethics committees.

2.2 | Stationary Time and Physical Activity

Physical activity for each participant was assessed using the ActiGraph GT1M uniaxial accelerometer (ActiGraph, Pensacola, USA), which recorded activity counts as the sum of acceleration and deceleration along the vertical axis. The methods for processing accelerometer data have been described in detail previously (Dunlop et al. 2011). Research staff personally fitted participants with the accelerometer during an in-person visit, providing standardized instructions to ensure proper placement and wear. Participants were instructed to wear the device on a belt at their natural waistline, aligned with their right axilla, from morning until bedtime, excluding water-based activities, for a consecutive seven-day period (Dunlop et al. 2011). The accelerometers were set to record activity data in 60s epochs at a sampling frequency of 30 Hz (Dunlop et al. 2011). Participants were required to accumulate a minimum of 10-h of wear time per day, which did not need to be continuous and could be spread throughout the day. Non-wear time was defined as periods of over 90-min with zero activity counts (Song et al. 2010). Physical activity intensity was classified using the National Cancer Institute's thresholds, with stationary time set at 0–99 counts per minute, light physical activity (LPA) at 100–2019 counts per minute, and MVPA at 2020 or more counts per minute (Troiano et al. 2008). For example, slow walking (~0.7–1.0 m/s, equivalent to ~40 - < 100 steps per minute (Tudor-Locke et al. 2019) or 1.5–2.9 metabolic equivalents (Ainsworth et al. 2011)) would be considered LPA. MVPA includes higher-intensity activities such as brisk walking or jogging. Brisk walking (≥ 1.2 m/s, equivalent to > 100 steps per minute (Tudor-Locke et al. 2019), or ≥ 3.0 METs (Ainsworth et al. 2011)) would be classified as MVPA. Thus, activities such as walking can span different intensity categories depending on their pace, with slow walking typically categorised as LPA and brisk walking as MVPA. Although these thresholds were developed in healthy adults and are not specific to osteoarthritis (Troiano et al. 2008), they serve as reasonable heuristic indicators of activity intensity. Moderate and vigorous activities were combined because of insufficient time spent in vigorous activity for separate analyses. Stationary time was used as a term due to the inability of waist-worn monitors to distinguish quiet standing from sedentary postures.

2.3 | Movement Phenotypes

Total stationary time was calculated by subtracting the total physical activity time from the total accelerometer wear time per day in minutes and corresponded to 0–99 activity counts per minute, and total daily wear time was the summation of time spent in stationary time, LPA, and MVPA. Total MVPA and stationary time were normalised to percentage of total wear time and participants were organised into tertiles at baseline (OAI V06 timepoint). Participants were grouped based on the possible combinations of tertiles in percent-MVPA and percent-stationary time at baseline (Table 1). The three groups consisted of individuals in the highest tertile of MVPA and lowest tertile of stationary time (high activity, low stationary; HALS), individuals in the highest tertile of MVPA and stationary time (high activity, high stationary; HAHS), and individuals in the lowest tertile of MVPA and highest tertile of stationary time (low activity, high stationary; LAHS). Due to an insufficient number of individuals in the lowest tertiles of MVPA and stationary time, this group was not included in analyses. Furthermore, because of the high daily time spent in LPA and stationary time in this sample, no participants satisfied the high light physical activity and high stationary time group; therefore, light physical activity was not included in the analyses.

TABLE 1 | Participant group allocation based on tertile grouping.

	MVPA tertile	ST tertile
Group		
High MVPA; low ST	3	1
High MVPA; high ST	3	3
Low MVPA; high ST	1	3

Note: Tertile 3 represents the highest tertile. Tertile 1 represents the lowest tertile.
Abbreviations: MVPA = moderate-to-vigorous physical activity; ST = stationary time.

2.4 | Gait Speed

Participants completed a 20-m walk test to assess their usual walking speed (Nevitt, Felson, and Lester 2006). The walking course was set up in an unobstructed corridor with cones marking the start and end of the 20-m length. Participants were instructed to walk at their usual pace and were required to take three steps past the orange cone at the end of the course before stopping. The test was conducted twice, with participants walking back in the opposite direction for the second trial. Each participant completed two walking trials and gait speed was calculated as the average between trials. The 20-m walk test was selected as a measure of gait speed, which has been linked to the ability to ambulate safely in the community (Andrews et al. 2010), and increased risk of mortality (Studenski et al. 2011). Gait speed was calculated at baseline (OAI V06 timepoint) and four-year follow-up (OAI V10 timepoint). Only participants who completed the 20 m walk were included in the analysis.

2.5 | 400 m Walk Test

Participants completed a 400 m walk test if they met specific eligibility criteria. Prior to testing, participants completed a 20-m walk to assess their ability to walk independently. Those unable to complete the 20-m walk or who had a radial pulse below 40 bpm or above 110 bpm, systolic blood pressure above 180 mm Hg, diastolic blood pressure above 100 mm Hg, or required supplemental oxygen, a walker or four-prong cane were excluded from the test. During the 400 m walk, participants were required to walk 10 laps of a 20-m course. Heart rate and symptoms were monitored throughout the test, and if heart rate exceeded 135 bpm, participants were instructed to slow down. The test was stopped if heart rate exceeded 135 bpm a second time or dropped below 40 bpm, or if participants reported chest pain, shortness of breath, dizziness, or leg pain. The 400 m walk time is positively correlated with $\dot{V}O_2$ max assessments, and was included as a surrogate measure of cardiorespiratory fitness (Gabriel et al. 2010). The 400 m walk was calculated at baseline (OAI V06 timepoint) and four-year follow-up (OAI V10 timepoint). Only participants who completed the entire 400 m walk were included in the analysis.

A total of 3 and 10 individuals were unable to complete the test at baseline and four-year follow-up, respectively.

2.6 | Five-Time Repeated Chair Stand

Participants performed a five-time repeated chair stand test to assess lower extremity strength. This test required participants to stand from a seated position five times as quickly as possible, with the total time recorded. Prior to the test, participants were instructed to cross their arms over their chest and complete the standing without using their arms for assistance. If participants were unable to arise without using their arms, the test was not attempted. A demonstration of two chair stands was provided, emphasising full standing and sitting positions. Participants were instructed to perform five consecutive chair stands as quickly as possible upon the command 'Go,' with timing starting when they began to rise. If participants were unable to perform the stands correctly, such as failing to achieve full standing or using momentum, the test was paused, and the procedure was re-demonstrated before a second trial was attempted. If participants stopped before completing five stands, they were asked if they could continue, and timing resumed if they confirmed. A second trial was conducted after a two-minute rest, unless the participant refused or was unable to continue. The five-time repeated chair stand test was included as an indicator of lower extremity strength (Muñoz-Bermejo et al. 2021), and was calculated at baseline (OAI V06 timepoint) and four-year follow-up (OAI V10 timepoint). Only participants who completed the entire five-time repeated chair stand were included in the analysis. A total of 13 patients were unable to complete the test at baseline and four-year follow-up, respectively.

2.7 | Statistical Analyses

Demographics and clinical characteristics were summarised using means and standard deviations or counts and percentages, depending on the type of outcome. One way analysis of variance models were used to determine differences in baseline participant demographics and clinical characteristics between activity phenotype groups; normality and equal variance were addressed using the Kolmogorov–Smirnov and Levene tests, respectively. Three 3×2 (group by time) mixed methods analysis of covariance models were used to assess group by time interactions and main effects for gait speed, 400 m walk test, and five-time repeated chair stand test between groups at baseline and four-year follow-up. Each model was adjusted for age and sex. An $\alpha = 0.05$ was set to indicate statistical significance for all tests and between group effect sizes were also calculated and interpreted using Cohen's *d*. Bonferroni pairwise comparisons were used for *post-hoc* testing with six possible comparisons, generating a new alpha level of $\alpha = 0.008$. Statistical analyses were completed using SPSS (Version 28.0, IBM Corp., Armonk, NY, USA).

3 | Results

A total of 442 individuals with or at risk of knee osteoarthritis were included in this study. Individuals in the lowest tertile of MVPA were older ($p < 0.001$), had a higher BMI ($p < 0.001$), spent less time in MVPA ($p < 0.001$), and had shorter average accelerometer wear time at baseline ($p < 0.001$) compared to individuals in the highest tertile of MVPA (Table 2).

TABLE 2 | Demographics and clinical characteristics (n = 442).

	HALS (n = 248)	HAHS (n = 60)	LAHS (n = 134)
Age (years)	60 ± 7	61 ± 9	71 ± 8[b]
BMI (kg/m^2)	27.3 ± 4.3	27.7 ± 4.1	29.6 ± 5.1[b]
Sex, no. of females (%)	119 (48)	10 (17)[a]	61 (45)[c]
Wear minutes (min/day)	911.3 ± 78.4	909.1 ± 79.9	880.0 ± 79.3[b]
Stationary time (min/day)	510.7 ± 71.4	669.7 ± 62.3[a]	670.3 ± 63.5[a]
Stationary time (% of wear time)	56.0 ± 6.0	74.6 ± 2.3[a]	76.3 ± 3.8[a]
Moderate to vigorous activity (min/day)	41.6 ± 22.4	36.5 ± 12.2[a]	2.4 ± 1.75[b]
Moderate to vigorous activity (% of wear time)	4.7 ± 2.4	4.0 ± 1.3[a]	0.3 ± 0.18[b]
Baseline gait speed (m/s)	1.43 ± 0.17	1.44 ± 0.17	1.26 ± 0.17
Four-year gait speed (m/s)	1.37 ± 0.18	1.38 ± 0.18	1.18 ± 0.18
Baseline 400 m walk (s)	282.7 ± 39.9	273.3 ± 32.9	335.6 ± 50.3
Four-year 400 m walk (s)	292.6 ± 38.9	285.8 ± 43.5	360.4 ± 66.4
Baseline repeated chair stand (s)	9.3 ± 2.4	9.2 ± 2.2	10.7 ± 2.8
Four-year repeated chair stand (s)	9.2 ± 2.4	9.2 ± 2.3	11.4 ± 3.1

Note: Values represent means ± standard deviations, unless otherwise indicated. Only baseline demographics and physical activity data were assessed for statistical difference in this table. All accelerometry data are from baseline.
Abbreviations: BMI = body mass index; HAHS = high activity high stationary; HALS = high activity low stationary; LAHS = low activity low stationary; Min = minutes; MVPA = moderate-to-vigorous physical activity; ST = stationary time.
[a]Indicates statistical difference from HALS.
[b]Indicates statistical difference from both HALS and HAHS.
[c]Indicates statistical difference from HAHS.

3.1 | Gait Speed

For gait speed, averaged group data at baseline and four-year follow-up are presented in Table 2. After covarying for age and sex, all groups exhibited similar decreases in gait speed over four-years (time effect: $p < 0.001$; Figure 1). Compared to individuals in the LAHS group, individuals in the HALS group had faster gait speed at baseline (HALS vs. LAHS mean difference: 0.17 m/s, 95% CI [0.13,0.20], $p < 0.001$, $d = 0.96$) and four-year follow-up (HALS vs. LAHS mean difference: 0.18 m/s, 95% CI [0.15,0.22], $p < 0.001$, $d = 1.00$). Further, compared to individuals in the LAHS group, individuals in the HAHS group walked faster at baseline (HAHS vs. LAHS mean difference: 0.17 m/s, 95% CI [0.12,0.22], $p < 0.001$, $d = 1.01$) and four-year follow-up (HAHS vs. LAHS mean difference: 0.20 m/s, 95% CI [0.14,0.25], $p < 0.001$, $d = 1.06$) (Figure 1). There were no differences in gait speed between the HALS and HAHS groups at baseline (HALS vs. HAHS mean difference: −0.01 m/s, 95% CI [−0.05,0.04], $p = 0.883$, $d = 0.03$) or four-year follow-up (HALS vs. HAHS mean difference: −0.02 m/s, 95% CI [−0.06,0.04], $p = 0.560$, $d = 0.10$).

3.2 | 400 m Walk Test

For the 400m walk test, averaged group data at baseline and four-year follow-up are presented in Table 2. After covarying for age and sex, individuals in the HALS group had faster 400m walk time at baseline (HALS vs. LAHS mean difference: −52.8s, 95% CI [−63.1,−43.5], $p < 0.001$, $d = 1.21$) and four-year follow-up (HALS vs. LAHS mean difference: −67.8s, 95% CI [−81.3,−55.8.0], $p < 0.001$, $d = 1.35$) compared to individuals in the LAHS group. Furthermore, compared to individuals in the LAHS group, individuals in the HAHS had faster 400m walk time at baseline (HAHS vs. LAHS mean difference: −62.3s, 95% CI [−73.8,−49.7], $p < 0.001$, $d = 1.36$) and four-year follow-up (HAHS vs. LAHS mean difference: −74.6 s, 95% CI [−90.7,−58.6], $p < 0.001$, $d = 1.23$) (Figure 2). There were no differences in 400m walk time between the HALS and HAHS groups at baseline (HALS vs. HAHS mean difference: 9.44s, 95% CI [−1.12,18.9], $p = 0.08$, $d = 0.24$) or four-year follow-up (HALS vs. HAHS mean difference: 6.80 s, 95% CI [−5.71,18.54], $p < 0.274$, $d = 0.17$).

3.3 | Five-Time Repeated Chair Stand

For the five-time repeated chair stand test, averaged group data at baseline and four-year follow-up are presented in Table 2. After covarying for age and sex, individuals in the HALS group had faster five-time repeated chair stand times at baseline (HALS vs. LAHS mean difference: −1.37s, 95% CI [−1.93,−0.81], $p < 0.001$, $d = 0.54$) and four-year follow-up (HALS vs. LAHS mean difference: −2.18s, 95% CI [−2.79,−1.54], $p < 0.001$, $d = 0.81$) compared to individuals in the LAHS group. Furthermore, compared to individuals in the LAHS group, individuals in the HAHS group had faster five-time repeated chair stand times (HAHS vs. LAHS mean difference: −1.51 s, 95% CI [−2.24,−0.83], $p < 0.001$, $d = 0.57$) and four-year follow-up (HAHS vs. LAHS mean difference: −2.15 s, 95% CI [−2.96,−1.40], $p < 0.001$, $d = 0.75$) (Figure 3). There were no differences in chair stand time between the HALS and HAHS groups at baseline (HALS vs. HAHS mean difference: 0.13 s, 95% CI [−0.48,0.75], $p = 0.687$, $d = 0.06$) or four-year follow-up (HALS vs. HAHS mean difference: 0.02 s, 95% CI [−0.71,0.62], $p = 0.955$, $d = 0.01$).

4 | Discussion

The results of this study document an association between higher levels of MVPA and improved physical function in individuals with or at risk of knee osteoarthritis regardless of stationary time. Specifically, those in the highest tertile of MVPA regardless of stationary time exhibited better outcomes in gait speed, the 400 m walk, and the repeated chair stand tests compared to individuals with the lowest MVPA and highest stationary time at baseline and these better functional outcomes remained over four-years. These findings support the growing body of evidence highlighting the importance of increasing

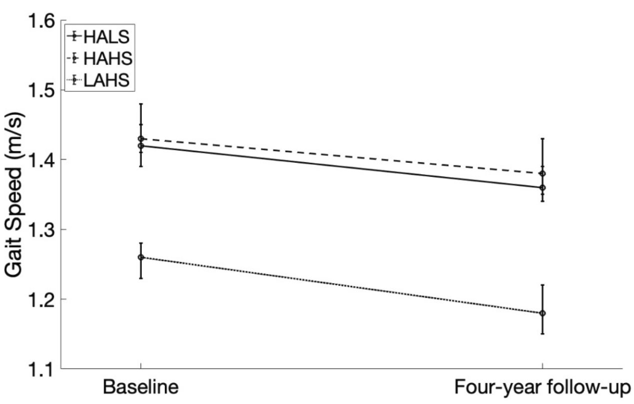

FIGURE 1 | Means and 95% confidence intervals for gait speed at baseline and four-year follow-up for individuals in the highest tertile of MVPA and lowest tertile of stationary time (solid line), highest tertile of MVPA and highest tertile of stationary time (dashed line) and lowest tertile of MVPA and highest tertile of stationary time (dotted line). HAHS = high activity high stationary; HALS = high activity low stationary; LAHS = low activity low stationary.

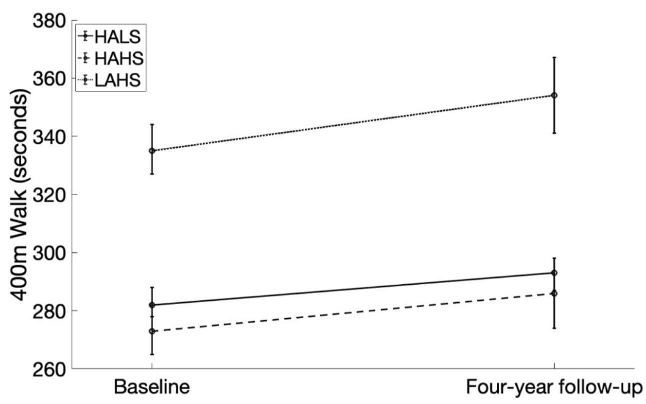

FIGURE 2 | Means and 95% confidence intervals for 400 m walk time at baseline and four-year follow-up for individuals in the highest tertile of MVPA and lowest tertile of stationary time (solid line), highest tertile of MVPA and highest tertile of stationary time (dashed line) and lowest tertile of MVPA and highest tertile of stationary time (dotted line). HAHS = high activity high stationary; HALS = high activity low stationary; LAHS = low activity low stationary.

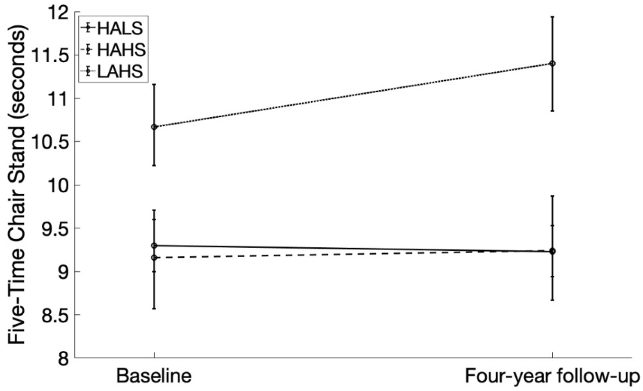

FIGURE 3 | Means and 95% confidence intervals for five-time repeated chair stand scores at baseline and four-year follow-up for individuals in the highest tertile of MVPA and lowest tertile of stationary time (solid line), highest tertile of MVPA and highest tertile of stationary time (dashed line) and lowest tertile of MVPA and highest tertile of stationary time (dotted line). HAHS = high activity high stationary; HALS = high activity low stationary; LAHS = low activity low stationary.

physical activity for individuals with or at risk for knee osteoarthritis, substantiating that more time in MVPA rather than stationary time may be particularly useful for attenuating the decline in physical function in this population.

Our results align with previous research that links higher MVPA levels to better functional outcomes, as seen in both performance-based and self-reported measures of function and disability (Sliepen et al. 2018; Song et al. 2018). The differences in gait speed, 400 m walk time and repeated chair stand across MVPA tertiles reinforce the established role of MVPA in preserving and improving mobility in older adults and those with joint impairments, such as knee osteoarthritis. Interestingly, stationary time did not appear to have an impact on functional outcomes as long as individuals were in the highest tertile of MVPA. Consistent with previous work that found that after controlling for total MVPA, stationary time was not associated with objective functional performance including gait speed, rising from a chair or grip strength (Cooper et al. 2015; van der Velde et al. 2017; Walker et al. 2021). These findings suggest that maintaining high levels of MVPA may offset the potential negative effects of prolonged stationary time on functional outcomes, highlighting the critical importance of regular, sustained physical activity in promoting mobility and physical function among older adults with knee osteoarthritis.

It is important to note that for individuals in the LAHS group at baseline, their functional outcome scores after four-years were indicative of more severe functional limitations. A gait speed of 1.2 m/s has been reported as the minimum speed required for safe community ambulation (Andrews et al. 2010) and has often been used as a criterion measure indicating functional decline (Fenton et al. 2018). Over four-years, individuals in the LAHS group were found to have a gait speed below 1.2 m/s, indicating a potential functional limitation and difficulty to maintain independence during community ambulation (Andrews et al. 2010). Furthermore, Newman and colleagues (2006) reported that individuals who had 400 m walk times above 360 s had a ~3-fold increase in risk of mortality compared to individuals who had 400 m walk times below 290 s (Newman et al. 2006). Individuals in the LAHS group met this 360 s mark after four-years, while individuals in the HALS and HAHS groups were either just above or below the 290 s cut-off. These findings suggest that low MVPA and high stationary time are associated with a trajectory of declining functional capacity over time, potentially placing individuals at greater risk of adverse health outcomes. Maintaining higher levels of MVPA may thus be crucial for supporting functional independence and reducing mortality risk.

Clinically, these findings have important implications for the management of knee osteoarthritis. Current physical activity guidelines recommend 150-min of MVPA per week, and the results from the current study support that on average, individuals in the highest tertiles of MVPA achieved these recommendations; however, regardless of MVPA tertile allotment, similar decreases in gait speed, 400-m walk, and repeated chair stand over four-years were noted. Being more physically active appears to give a larger buffer at baseline, where an age-related decline in function may not result in clinically meaningful functional limitation. Therefore, continuous efforts are needed to maintain mobility as the disease progresses. This reinforces the importance of long-term behavioural strategies that incorporate physical activity management. While the results demonstrate that individuals in the highest tertiles of MVPA exhibit better functional performance, achieving similar levels of MVPA may not be a realistic short-term goal for those in the lowest tertile. Therefore, for individuals who find it challenging to engage in sustained higher-intensity exercise, it may be more practical to recommend incorporating brief, vigorous bursts of physical activity throughout daily routines (Vigorous intermittent lifestyle physical activity) as a more manageable approach to increasing overall physical activity until sustained MVPA becomes feasible (Stamatakis et al. 2021).

A key strength of this study is the use of objective accelerometer-based measures of physical activity and stationary time, which reduce the risk of recall bias often associated with self-reported activity measures. Additionally, the sample size and prospective design allow for robust examination of long-term functional outcomes in a population-based cohort. However, several limitations should be noted. Physical activity data were collected cross-sectionally over a one-week period, which limits the ability to predict changes in physical activity behaviour over time or establish causality and raises the potential for reverse causality, where functional limitations may influence physical activity levels. Furthermore, the current waist-worn accelerometer used cannot distinguish between stationary time and detailed sedentary time or short-duration sleep (i.e., napping). While accelerometry has inherent limitations, such as its inability to capture certain types of activities (e.g., water-based exercises), it remains the criterion standard for measuring physical activity in free-living environments (Westerterp 2014).

5 | Conclusions

Being in the highest tertile of MVPA regardless of stationary time was associated with better functional outcomes in gait speed, 400 m walk times and five-time repeated chair stand test over four-years. Higher levels of stationary time do not negatively influence functional performance as long as higher numbers of MVPA levels (~30 min/day) are achieved.

Author Contributions

C.H., M.W.O. and R.M. participated in the design of the study, all authors contributed to data analysis and interpretation of the results. C.H. wrote the first draft and conducted all statistical analyses. All authors contributed to the editing and manuscript writing. All authors have read and approve the final version of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data used for analyses in this paper are publicly available at https://nda.nih.gov/oai.

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