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# Chronic Pain Characteristics and Gait in Older Adults: The MOBILIZE Boston Study II

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## Abstract

**Objective:** To investigate a proposed cognitively-mediated pathway whereby pain contributes to gait impairments by acting as a distractor in community-living older adults.

**Design:** A cross-sectional study of a population-based cohort of older adults.

**Setting:** Urban and suburban communities in a large metropolitan area.

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Conflict of Interest Statement

No potential conflict of interest was reported by the authors.

**Participants:** Community-living participants (n=302) aged 70 years and older recruited from a previous population-based cohort.

**Interventions:** Not applicable.

**Main Outcome Measures:** Gait parameters including gait speed, stride length, double support and swing characteristics, and variability, were assessed under single and dual-task conditions involving cognitive challenges (e.g. counting backwards). A joint pain questionnaire assessed pain distribution in the back and major joints. We examined pain-gait relationships using multivariable linear regression and bootstrapping mediation procedures.

**Results:** Forty-three percent of participants had pain in 2 or more musculoskeletal sites. Pain distribution was related to slower gait speed and other gait characteristics for all gait conditions. Associations persisted after adjustment for age, sex, education, BMI, medication, and vision. Decrements in gait measures related to pain were comparable to decrements in gait related to dual-task conditions. There were no differences in dual-task cost among the pain distribution groups. Adjusted for confounders, pain-gait relationships appear mediated by selective attention.

**Conclusions:** These findings suggest that chronic pain contributes to decrements in gait including slower gait speed and that it operates through a cognitively-mediated pathway. Further research is needed to understand the mechanisms via pain alters mobility and to develop interventions to improve mobility among older adults with chronic pain.

### Keywords

Mobility limitation; gait; cognitive function; chronic pain; aging

## INTRODUCTION

The high prevalence of chronic pain in older adults contributes to significant burden in terms of daily functioning and use of health care services. More than half of older people report bothersome pain and 75% of this group reports pain in multiple sites (1). Chronic pain is the most common symptom contributing to disability in daily self-care activities among older women (2). Accumulating evidence points to the disabling consequences of chronic pain in older adults, with multisite pain conferring the greatest risk for disability and falls (3–5).

Despite the general awareness of the problem of chronic pain in aging, little is known about gait changes related to chronic musculoskeletal pain and the mechanistic pathways connecting pain with compromised mobility in the older population. A good deal of research has demonstrated the importance of intact cognitive functioning for stable gait and avoidance of falls in older adults (6). In addition, when asked to perform a cognitive dual-task while walking, older adults tend to slow down and show a more variable gait pattern and increased gait modifications (dual-task costs) are associated with an increased risk of falls (7). Recent evidence also suggests brain changes in the white matter microstructure and macrostructure in older adults with musculoskeletal pain compared to those without pain (8). With accumulating evidence about the impact of chronic pain on cognition (9,10), it is possible that chronic pain may lead to changes in cognition and thus lead to mobility limitations. For example, consistent with Eggleston's work on pain's impact on attentional

resources, pain may act as a distractor and thus may also disrupt mobility (11). Other possible underlying mechanisms that could explain the relationship between pain and gait limitations could include musculoskeletal pathologies such as arthritic back and joint changes (12,13). Also, chronic pain is closely linked to depression, which can contribute to falls and mobility difficulties (3,14,15).

Gait performance can be classified into multiple domains, including, for example, pace, phase, and variability (16). Evidence supports the idea that these domains of gait are clinically meaningful in terms of neuromotor control of mobility, not only for their impact on fall risk but also related to chronic diseases such as osteoarthritis, dementia and Parkinson's Disease (17,18). In addition, gait phase and variability parameters are associated with increased fall risk (19). Dual-task costs refer to the changes in gait performance from usual walking to walking with a concurrent cognitive challenge, such as counting backward. Dual-task costs are shown to be substantially greater in older adults, particularly those with mobility limitations or poorer executive function (20). Previous studies have demonstrated differential effects of cognitive dual-tasks on gait parameters (21,22). Under the dual-task condition, slowing of gait speed was found among all groups including young adults, and older fallers and older non-fallers (21,22). However, greater dual-task costs were found among older adult fallers in the domain of gait variability, but not among young and old non-fallers (21), suggesting that fall risk may be linked to more variability in gait performance detected under dual-task conditions. Similar to dual-task walking, pain may interfere with walking by serving as a distractor, placing demands on attentional resources, and thus interfering with safe mobility.

The purpose of this paper is to investigate the relationship between pain characteristics and gait performance during a usual-walking condition as well as during a dual-task, attention-demanding walk. We hypothesized that pain would function as a distractor during walking, leading to decrements in gait parameters similar to those observed with cognitive challenges.

## METHODS

The Maintenance of Balance, Independent Living, Intellect, and Zest in the Elderly (MOBILIZE) Boston Study II (MBSII) is a follow-up assessment of the original MOBILIZE Boston Study I (MBSI), a longitudinal population-based study of older adults living in Boston area communities (23). MBSII took place approximately 6 years after MBSI's baseline assessment. MBSI participants (n=765) were recruited door-to-door from 2005 to 2008. The original eligibility criteria for MBSI included the following: aged 70 years or older, able to communicate in English, plan to be in the area for two years, and able to walk 20 feet without help from another person. Spouses and domestic partners of eligible enrollees who were 65 years and older and otherwise eligible were allowed to participate. Exclusion criteria for MBSI included diagnosis of terminal disease, severe vision or hearing deficits, and moderate to severe cognitive impairment (Mini-Mental State Examination<18).

MBSII re-enrolled the original MBSI cohort from 2012–2014 (n=354). The eligibility criteria for MBSII included: residing in the Boston area, being free of severe cognitive impairment, and able to walk without personal assistance. Participants were excluded from

MBSII if they had experienced severe health deterioration or were living in a nursing home. MBSII participants' provided informed consent at the start of the assessment visit. The institutional review boards of the Hebrew SeniorLife and the University of Massachusetts Boston approved all protocols for the study including the informed consent procedures. A detailed description of the original MBSI design and methods was published previously (23).

## Measurements

The MBSII assessment was conducted in 2 parts, a telephone health interview followed within 2 weeks by a study clinic visit. The health interview included questions about health behaviors, physical function, and medical conditions including pain symptoms. The study clinic visit included physical assessment, gait and cognitive test batteries and medication review. Details of the methods were described previously (22,23). Sociodemographic information (age, sex, race and education) was collected in the MBSI.

Data for this cross-sectional study included sociodemographic characteristics (assessed in MBSI), health status, pain assessment, gait performance, height and weight, activities of daily living (ADL), chronic conditions (self-reported stroke and heart disease; osteoarthritis and diabetes by disease algorithms), medication review (psychoactive and analgesic medication use) and vision testing (assessed in study clinic visit) (24).

Gait performance was assessed using a 16-foot sensored GAITRite® gait mat (CIR Systems, Inc., Franklin, NJ). Participants walked back and forth on the mat at their normal pace under three conditions: single-task (usual walking) and two dual-task conditions (easy dual-task and hard dual-task) in random order, with at least one minute of rest breaks between the 3 conditions. During the dual-task gait conditions, participants walked while performing cognitive tasks designed to demand attention. The cognitive tasks for easy and hard dual-task tests were selected based on each participant's performance during seated practice sessions before the gait tests. Participants were asked to complete up to 5 cognitive tasks, starting with the most challenging: serial 3s, 5s, 1s, counting backward from 100; serial 1s counting forward from 1; naming items found in a supermarket (21,22). When a participant provided three correct answers within 15 seconds, that task and the next easier task were selected as the hard and easy dual-tasks, respectively. Participants were not explicitly instructed to pay attention to either the walking or to the cognitive task. Participants completed 2 walking trials for each walking condition where each trial comprised 3 passes on the 16-foot gait mat.

The gait mat software measures location and timing to calculate gait parameters in 3 domains: *pace* (e.g. gait speed, stride length), *phase* (e.g. swing time percent, double support time percent), and *variability* (e.g. stride length variability, and swing time variability). The coefficient of variation (CV) was used as a measure of gait variability (SD/mean x 100). Dual-task cost was calculated for easy task (single-task to easy dual-task) and hard task (single-task to hard dual-task) accordingly to a formula $DTC\ [\%] = 100\ \times\ \frac{(\mathrm{Sing}le - Task\ Score) - (Dual - Task\ Score)}{\mathrm{Sing}le - Task\ Score}$ (25) when a higher value represented a better gait characteristic (gait speed, stride length, and swing time percent) and

$DTC\ [\%] = 100 \times \frac{(Dual-Task\ Score)-(Single-Task\ Score)}{Single-Task\ Score}$ when a lower value represented better gait characteristic (double support time percent, stride length variability, and swing time variability). Thus, positive, greater value represents greater dual-task cost (worse) for all gait measures. These gait measures have been validated and used in previous studies of gait in older adults (20,26–30).

Chronic musculoskeletal pain was assessed and defined as pain present for 3 or more months in the previous year and present in the previous month. Pain location was measured using a 13-item joint pain questionnaire that assessed pain in the back and five joint areas (feet, knees, hips, shoulders, hands/wrists) (23). The pain measure we used has been found previously to predict falls and disability in older adults (3,5).

Cognitive function, specifically attentional abilities, was assessed using the Test of Everyday Attention (TEA). The TEA assesses multiple domains of attention in adults (31) and we used 4 TEA subscales: Visual Elevator (attentional switching), Map Search (visual selective attention), Telephone Search (selective attention) and Telephone Search While Counting with dual-task (sustained and divided attention (32,33)). The TEA test including the test domain have been validated in both younger and older adults (32).

### Statistical Analysis

Demographic and health characteristics were examined according to pain distribution, using chi-square tests to evaluate group differences. Gait measures under single and dual-task conditions and dual-task costs were examined according to pain distribution; tests for trend were performed using ANOVA and unadjusted general linear models.

We used multivariable linear regression models adjusting for potential confounders including sociodemographic (age, sex, race, education) and health characteristics (body mass index (BMI) categories (34), psychoactive and analgesic medication usage and vision impairment) to examine the relationships between pain and gait measures. There were 10 participants (3%) with missing information on covariates who were excluded from the multivariable models. Gait phase and variability parameters were highly skewed and thus were log-transformed for the analysis.

For each gait condition, separate mediation analyses were performed to elucidate whether the associations between pain and gait performance were mediated by measures of attention. Mediation was evaluated based on the Baron and Kenny method, by examining the indirect effect of cognitive function on the pain and gait relationships (35). The CAUSALMED procedure (SAS 9.4, Cary, NC), was used to estimate mediation effects using 1000 bias-corrected bootstrap samples (36) and two separate models were performed (multisite pain vs. no pain; single site pain vs. no pain). Analyses were conducted using SAS and STATA SE 15.0 (College Station, TX).

## RESULTS

Of the 354 MBSII participants, 302 completed the gait assessment. Those who did not complete the gait assessment (n=52) were significantly older (p=0.02), had more activities of

daily living (ADL) difficulty ($p<0.001$), and greater pain severity ($p=0.04$) compared to those who completed the gait assessment.

The average age of the 302 participants was 84 years (range, 71–101). About two-thirds of participants (64%) were women, 57% had a college degree and 80% were white. We observed a weak inverse association of education with pain distribution ($p=0.06$) and higher prevalence of obesity and overweight among those with multisite pain compared to those with single site or no pain ($p=0.05$, Table 1).

Participants who had multisite pain consistently performed worse than those who had no pain or single site pain across all gait conditions and gait characteristics. For example, in the single-task walk, those with multisite pain had slower gait speed than those with single site pain or no pain (1.00±0.23 m/second, 0.87±0.27 m/second, and 0.84±0.24 m/second, respectively, Table 2). Similar decrements according to pain distribution were observed with gait measures during dual-task conditions. After adjusting for sociodemographic and health characteristics, pain distribution was independently associated with poorer performance in most gait measures (Table 3).

In general, the decrements in gait performance from the single-task to the cognitively difficult dual-task condition were comparable to the decrements observed with greater pain distribution within each of the single and dual-task conditions. There were no differences in dual-task costs among pain distribution groups (no pain, single site pain, and multisite pain). Dual-task costs of gait characteristics were comparable among those with no pain, single site pain and multisite pain (Table 4). After adjusting for sociodemographic and health characteristics, pain distribution was not associated with greater dual-task cost in gait measures with one exception, for single site pain with swing time percent, where single site pain was associated with greater dual-task cost for swing time percent compared to the no pain group (Table 5).

We examined measures of attention as possible mediators of the pain and gait relationship. We found that one of the 3 domains of attention, selective attention as measured by the telephone search test, mediated the relation between pain distribution and several gait characteristics, and the extent of the mediation effect was greater for single site (Percent mediated, 0–56% ) than multisite pain (Percent mediated, 8–33%) in relation to gait (Supplementary Tables 1–2). We did not observe mediating effects of measures of sustained and divided attention or attentional switching on relationships between pain and gait parameters (data not shown).

## DISCUSSION

In this population of community-dwelling older adults, pain distribution was strongly associated with poorer performance in most gait measures, including gait speed, stride length, and time spent with both feet on the ground as a percent of the gait cycle (double support time percent). In addition, the performance decrements related to cognitive challenges were comparable to decrements observed among participants reporting greater pain during the usual (single-task) walks. However, we did not find that dual task costs were

greater among those with pain compared to those without pain. Still, the evidence from our mediation analysis suggests that selective attention is a mediator of the pain-gait associations, supporting the idea that chronic pain may affect gait through a cognitively-mediated pathway. In summary, the findings point to a substantial impact of chronic pain on mobility in older adults.

Our results generally are consistent with the few previous studies that examined the relationship between pain and gait characteristics. In cross-sectional studies of healthy non-disabled volunteers aged 65 years and older, investigators found both pain severity and multisite pain were associated with slow gait speed (n=176), while another study of a group of older volunteers (n=112) by the same investigators did not find an association between number of pain sites and gait characteristics (37,38). Notably, the prevalence of multisite pain was low in these volunteer samples compared to our older MBSII population. In a population-based study of older adults without disabilities, the presence of two sites of lower body pain was associated with slower gait speed after adjusting for potential confounders (39). To our knowledge, our study is the first to examine multisite pain in relation to gait characteristics under both single-task and dual-task conditions.

The evidence from our study supports our hypothesis, that the effect of chronic pain is similar to a cognitive challenge during walking, suggesting that chronic pain may function as a distractor in older adults while walking. In general, older adults who had multisite pain performed poorer across gait parameters compared to those with no pain. However, based on our findings regarding the impact of dual-tasking, multisite pain did not have an additive effect on dual-task cost. Also, we found that the intermediate pain group, those with single site pain, experienced the greatest dual task cost, compared to those without pain. The dual task cost, representing the combined effect of pain and a cognitive challenge during gait, was not greater than the independent effect of either pain or the dual-task gait condition. Older adults with multisite pain already have significantly slower gait speed and this may result in less apparent dual-task costs. This could also explain the pattern we observed in the multivariable dual-task cost and mediation analyses, where the greater dual-task cost and mediating effect of attention were a bit stronger among those with single site pain than with multisite pain.

Multisite pain may contribute to a decrement observed in gait performance that approximates that of a relatively challenging (i.e., “hard” in the present study) dual-task condition among participants with no pain. This usual walk decrement may be enough to place older adults with multisite pain at a substantial increased risk for falls, as reported previously (5). The gait performance during the dual-task walking performance of the older adults with multisite pain was again lower than that of persons without pain, making them even more vulnerable to falls and other mobility problems. Further research is needed to determine if there may be a threshold in gait performance whereby older adults with pain may be at much greater risk for falls.

Overall, our results are consistent with the current literature which supports the idea that gait and cognition are interrelated (7,40–42). The mediating effects of selective attention suggest that the impact of chronic pain on gait in older adults is not solely through a mechanical

pathway but also may operate through a cognitive pathway. Other deleterious cognitive effects of pain (10) could also be contributing to gait decrements, but have yet to be explored.

In addition to chronic pain being a distractor, older adults with chronic pain may attempt to avoid discomfort in specific load-bearing joints. These combined effects may lead to changes in gait including overall slowing, more variable stepping, and longer double support time percent. The longer double support time percent has also been observed in other conditions such as dementia (43) as well as conditions that have both cognitive and peripheral neuromotor effects such as Parkinson's disease (44), suggesting older adults with chronic pain may have similar gait adaptations. For older adults who have destabilizing conditions, it may be more stabilizing to lengthen the double support time in response to imbalance. Another consideration has to do with the directionality of the relationship between cognition and mobility, which cannot be confirmed using a cross-sectional approach. Recent evidence suggests there may be a bidirectional effect whereby mobility limitations also may contribute to poorer cognitive functioning over time (45).

Non-cognitive, peripheral neuromuscular impairments may also be contributing to differences in gait characteristics according to pain distribution and pain severity. In a cross-sectional study that had similar participant characteristics to MBSII, different neuromuscular attributes were found to be associated with gait speed between older adults with and without chronic back pain (46). Similarly, in another cross-sectional study examining lumbar mobility, investigators concluded that the relationship between lumbar mobility and functional performance were different between older adults with and without chronic low back pain (47). This suggests that older adults with pain may manifest different patterns of peripheral neuromuscular impairments and develop prioritization of different attributes in order to complete the same tasks compared to those without pain. An additional explanation may related to adaptations to fear and avoidance. A recent study reported an independent relationship between pain fear-avoidance and self-reported disability in older adults with back pain (48). Another potential contributor to avoidance, fear of falling, is associated with gait changes such as slower gait speed and reduced step length (49). Older adults with multisite pain may be particularly vulnerable to the impact of avoidance and fear of falling, and might also restrict their mobility.

Among the strengths of this research, the population-based cohort that is representative of older community-dwelling adults, contributes to the generalizability of our study findings. In addition, our study included measures of pain and gait characteristics using validated instruments, confirming the relationship between pain and gait characteristics in single and dual-task conditions. This is the first investigation to examine the impact of chronic musculoskeletal pain on a broad range of gait characteristics and how cognition may influence these relationship. This is an important step in developing a scientific basis for new strategies to improve mobility and reduce fall risk in older adults who live with chronic multisite pain.

### Study Limitations

There are limitations to our study that need to be considered. The cross-sectional design does not establish a temporal relation between pain and gait disturbance. Although we would expect that pain would have an immediate impact on gait, longitudinal studies are necessary to examine the causal relationship between pain and gait. Secondly, most participants in the study were among the oldest old in the population, those aged 80 or older, therefore, our findings may not generalize to the population aged 65 and older. However, given that the oldest old are more susceptible to cognitive decline and mobility limitations contributing to fall risks, this may be the best population in which to observe the detrimental effects of chronic pain on gait.

## CONCLUSIONS

In conclusion, chronic pain distribution is strongly associated with poor performance in gait, especially during walking that involves cognitively demanding tasks. Our findings suggest that although it may not have an additive effect, chronic pain may act similarly to a cognitive dual-task, and may be a distractor during walking in older adults, thereby contributing to mobility difficulties and risk for falls. Longitudinal research is needed to establish the causal pathway through which pain contributes to falls in older adults with multisite pain.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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## Abbreviations:

| | |
|---|---|
| **TEA** | Test of Everyday Attention |
| **BMI** | Body Mass Index |
| **ADL** | Activities of Daily Living |

## References

1. Patel KV, Guralnik JM, Dansie EJ, Turk DC. Prevalence and impact of pain among older adults in the United States: findings from the 2011 National Health and Aging Trends Study. Vol. 154, Pain. 2013 12;154(12):2649–57. [PubMed: 24287107]
2. Leveille SG, Fried L, Guralnik JM. Disabling symptoms: what do older women report?. Vol. 17, Journal of general internal medicine. 2002 10;17(10):766–73. [PubMed: 12390552]

3. Eggermont LHP, Leveille SG, Shi L, Kiely DK, Shmerling RH, Jones RN, et al. Pain characteristics associated with the onset of disability in older adults: the maintenance of balance, independent living, intellect, and zest in the Elderly Boston Study. Vol. 62, Journal of the American Geriatrics Society. 2014 6;62(6):1007–16. [PubMed: 24823985]
4. Shah RC, Buchman AS, Boyle PA, Leurgans SE, Wilson RS, Andersson GB, et al. Musculoskeletal pain is associated with incident mobility disability in community-dwelling elders. Vol. 66, The journals of gerontology. Series A, Biological sciences and medical sciences. 2011 1;66(1):82–8.
5. Leveille SG, Jones RN, Kiely DK, Hausdorff JM, Shmerling RH, Guralnik JM, et al. Chronic musculoskeletal pain and the occurrence of falls in an older population. Vol. 302, JAMA. 2009 11 25;302(20):2214–21. [PubMed: 19934422]
6. Amboni M, Barone P, Hausdorff JM. Cognitive contributions to gait and falls: evidence and implications. Vol. 28, Movement disorders : official journal of the Movement Disorder Society. 2013 9 15;28(11):1520–33. [PubMed: 24132840]
7. Montero-Odasso M, Verghese J, Beauchet O, Hausdorff JM. Gait and cognition: A complementary approach to understanding brain function and the risk of falling. Vol. 60, Journal of the American Geriatrics Society. 2012;60(11):2127–36. [PubMed: 23110433]
8. Cruz-Almeida Y, Rosso A, Marcum Z, Harris T, Newman AB, Nevitt M, et al. Associations of Musculoskeletal Pain With Mobility in Older Adults: Potential Cerebral Mechanisms. Vol. 72, The journals of gerontology. Series A, Biological sciences and medical sciences. 2017;72(9):1270–6.
9. Weiner DK, Rudy TE, Morrow L, Slaboda J, Lieber S. The relationship between pain, neuropsychological performance, and physical function in community-dwelling older adults with chronic low back pain. Vol. 7, Pain Medicine. 2006;7(1):60–70. [PubMed: 16533199]
10. van der Leeuw G, Eggermont LHP, Shi L, Milberg WP, Gross AL, Hausdorff JM, et al. Pain and cognitive function among older adults living in the community. Vol. 71, The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 2016;71(3):398–405.
11. Eggermont LHP, Penninx BWJH, Jones RN, Leveille SG. Depressive symptoms, chronic pain, and falls in older community-dwelling adults: The mobilize Boston study. Vol. 60, Journal of the American Geriatrics Society. 2012;60(2):230–7. [PubMed: 22283141]
12. Henriksen M, Graven-Nielsen T, Aaboe J, Andriacchi TP, Bliddal H. Gait changes in patients with knee osteoarthritis are replicated by experimental knee pain. Vol. 62, Arthritis Care and Research. 2010;62(4):501–9. [PubMed: 20391505]
13. Rutherford D, Baker M, Wong I, Stanish W. The effect of age and knee osteoarthritis on muscle activation patterns and knee joint biomechanics during dual belt treadmill gait. Vol. 34, Journal of Electromyography and Kinesiology. 2017;34(2017):58–64. [PubMed: 28411486]
14. Leveille SG, Bean J, Ngo L, McMullen W, Guralnik JM. The pathway from musculoskeletal pain to mobility difficulty in older disabled women. Vol. 128, Pain. 2007;128(1–2):69–77. [PubMed: 17055167]
15. Hausdorff JM, Peng CK, Goldberger AL, Stoll AL. Gait unsteadiness and fall risk in two affective disorders: A preliminary study. Vol. 4, BMC Psychiatry. 2004;4:1–7. [PubMed: 15018628]
16. Hollman JH, McDade EM, Petersen EC. Normative Spatiotemporal Gait Parameters in Older Adults. Vol. 34, Gait & posture. 2011;34(1):111–8. [PubMed: 21531139]
17. Hausdorff JM. Gait dynamics, fractals and falls: Findings meaning in the stride-to-stride fluctuations of human walking. Vol. 26, Hum Mov Sci. 2007;26(4):555–89. [PubMed: 17618701]
18. Mills K, Hunt MA, Ferber R. Biomechanical deviations during level walking associated with knee osteoarthritis: A systematic review and meta-analysis. Vol. 65, Arthritis Care and Research. 2013;65(10):1643–65.
19. Verghese J, Holtzer R, Lipton RB, Wang C. Quantitative gait markers and incident fall risk in older adults. Vol. 64, Journals of Gerontology - Series A Biological Sciences and Medical Sciences. 2009;64(8):896–901.
20. Hausdorff JM, Schweiger A, Herman T, Yogev-Seligmann G, Giladi N. Dual-task decrements in gait: contributing factors among healthy older adults. Vol. 63, The journals of gerontology. Series A, Biological sciences and medical sciences. 2008 12;63(12):1335–43.

21. Springer S, Giladi N, Peretz C, Yogev G, Simon ES, Hausdorff JM. Dual-tasking effects on gait variability: the role of aging, falls, and executive function. Vol. 21, Movement disorders : official journal of the Movement Disorder Society. 2006 7;21(7):950–7. [PubMed: 16541455]
22. Yogev G, Giladi N, Peretz C, Springer S, Simon ES, Hausdorff JM. Dual tasking, gait rhythmicity, and Parkinson's disease: Which aspects of gait are attention demanding? Vol. 22, European Journal of Neuroscience. 2005 9;22(5):1248–56. [PubMed: 16176368]
23. Leveille SG, Kiel DP, Jones RN, Roman A, Hannan MT, Sorond FA, et al. The MOBILIZE Boston Study: design and methods of a prospective cohort study of novel risk factors for falls in an older population. Vol. 8, BMC geriatrics. 2008 7 18;8:16. [PubMed: 18638389]
24. van der Leeuw G, Leveille SG, Dong Z, Shi L, Habtemariam D, Milberg W, et al. Chronic Pain and Attention in Older Community-Dwelling Adults. Vol. 66, Journal of the American Geriatrics Society. 2018 7 1;66(7):1318–24. [PubMed: 29876923]
25. Bock O Dual-task costs while walking increase in old age for some, but not for other tasks: An experimental study of healthy young and elderly persons. Vol. 5, Journal of NeuroEngineering and Rehabilitation. 2008;5:1–9. [PubMed: 18171465]
26. Allali G, Kressig RW, Assal F, Herrmann FR, Dubost V, Beauchet O. Changes in gait while backward counting in demented older adults with frontal lobe dysfunction. Vol. 26, Gait & posture. 2007 10;26(4):572–6. [PubMed: 17344044]
27. Chamberlin ME, Fulwider BD, Sanders SL, Medeiros JM. Does fear of falling influence spatial and temporal gait parameters in elderly persons beyond changes associated with normal aging? Vol. 60, The journals of gerontology. Series A, Biological sciences and medical sciences. 2005 9;60(9):1163–7.
28. Callisaya ML, Blizzard L, Schmidt MD, McGinley JL, Srikanth VK. Sex modifies the relationship between age and gait: a population-based study of older adults. Vol. 63, The journals of gerontology. Series A, Biological sciences and medical sciences. 2008 2;63(2):165–70.
29. Menz HB, Latt MD, Tiedemann A, Kwan MMS, Lord SR. Reliability of the GAITRite walkway system for the quantification of temporo-spatial parameters of gait in young and older people. Vol. 20, Gait & posture. 2004 8;20(1):20–5. [PubMed: 15196515]
30. Parmar V, Kumar AJS, Harper WM. Reliability of the GAITRite walkway system for the quantification of temporo-spatial parameters of gait in young and older people. Vol. 23, Gait & posture. 2006 6;23(4):523; author reply 524–5. [PubMed: 16005632]
31. Robertson IH, Ward T, Ridgeway V, Nimmo-Smith I. The structure of normal human attention: The Test of Everyday Attention. Vol. 2, Journal of the International Neuropsychological Society : JINS. 1996 11;2(6):525–34. [PubMed: 9375156]
32. van der Leeuw G, Leveille SG, Jones RN, Hausdorff JM, McLean R, Kiely DK, et al. Measuring attention in very old adults using the Test of Everyday Attention. Vol. 24, Neuropsychology, development, and cognition. Section B, Aging, neuropsychology and cognition. 2017 9;24(5):543–54.
33. Bate AJ, Mathias JL, Crawford JR. Performance on the Test of Everyday Attention and Standard Tests of Attention following Severe Traumatic Brain Injury. Vol. 15, The Clinical Neuropsychologist. 2003;15(3):405–22.
34. Summary E Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults: executive summary. Expert Panel on the Identification, Evaluation, and Treatment of Overweight in Adults. Vol. 68, The American Journal of Clinical Nutrition. 2018;68(4):899–917.
35. Baron RM, Kenny DA. The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. Vol. 51, Journal of personality and social psychology. 1986 12;51(6):1173–82. [PubMed: 3806354]
36. SAS Institute Inc. SAS/STAT ® 14.3 User's Guide The CAUSALMED Procedure [Internet]. Cary, NC: SAS Institute Inc.; 2017.
37. Sawa R, Doi T, Misu S, Saito T, Sugimoto T, Murata S, et al. The severity and number of musculoskeletal pain associated with gait in community-dwelling elderly individuals. Vol. 54, Gait and Posture. 2017;54:242–7. [PubMed: 28351745]

38. Asai T, Misu S, Sawa R, Doi T, Yamada M. Multi-chronic musculoskeletal pain is a useful clinical index to predict the risk of falls in older adults with normal motor function. Vol. 27, Aging Clinical and Experimental Research. 2015;27(5):711–6. [PubMed: 25753186]
39. Cruz-Almeida Y, Rosso A, Marcum Z, Harris T, Newman AB, Nevitt M, et al. Associations of musculoskeletal pain with mobility in older adults: potential cerebral mechanisms. Vol. 00, The Journals of Gerontology: Series A. 2017;00(00):1–7.
40. Yogev-Seligmann G, Hausdorff JM, Giladi N. The role of executive function and attention in gait. Vol. 23, Movement disorders : official journal of the Movement Disorder Society. 2008 2;23(3):329–42. [PubMed: 18058946]
41. Lamoth CJ, van Deudekom FJ, van Campen JP, Appels BA, de Vries OJ, Pijnappels M. Gait stability and variability measures show effects of impaired cognition and dual tasking in frail people. Vol. 8, Journal of NeuroEngineering and Rehabilitation. 2011;8(1):2. [PubMed: 21241487]
42. Lundin-olsson L, Nyberg L, Gustafson Y. Attention, frailty, and falls: the effect. Vol. 46, J AM Geriatr Soc. 1998;46(6):758–61. [PubMed: 9625194]
43. van Iersel MB, Hoefsloot W, Munneke M, Bloem BR, Rikkert MGO. Systematic review of quantitative clinical gait analysis in patients with dementia. Vol. 37, Zeitschrift fur Gerontologie und Geriatrie. 2004 2;37(1):27–32. [PubMed: 14991293]
44. Hass CJ, Malczak P, Nocera J, Stegemöller EL, Shukala A, Malaty I, et al. Quantitative normative Gait data in a large cohort of ambulatory persons with parkinson's disease. Vol. 7, PLoS ONE. 2012;7(8):4–8.
45. Best JR, Liu-Ambrose T, Boudreau RM, Ayonayon HN, Satterfield S, Simonsick EM, et al. An evaluation of the longitudinal, bidirectional associations between gait speed and cognition in older women and men. Vol. 71, J Gerontol A Biol Sci Med Sci. 2016;71(12):1616–23. [PubMed: 27069098]
46. Makris UE, Paul TM, Holt NE, Latham NK, Ni P, Jette A, et al. The relationship among neuromuscular impairments, chronic back pain, and mobility in older adults. Vol. 8, PM & R : the journal of injury, function, and rehabilitation. 2016 8;8(8):738–47.
47. Coyle PC, Velasco T, Sions JM, Hicks GE. Lumbar mobility and performance-based function: an investigation in older adults with and without chronic low back pain. Vol. 18, Pain medicine (Malden, Mass.). 2017;18(1):161–8.
48. Sions JM, Hicks GE. Fear-avoidance beliefs are associated with disability in older American adults with low back pain. Vol. 91, Physical therapy. 2011 4;91(4):525–34. [PubMed: 21350033]
49. Makino K, Makizako H, Doi T, Tsutsumimoto K, Hotta R, Nakakubo S, et al. Fear of falling and gait parameters in older adults with and without fall history. Vol. 17, Geriatrics and Gerontology International. 2017;17(12):2455–9. [PubMed: 28656737]

**Table 1.**

Participant characteristics according to pain distributions, 302 older adults, MOBILIZE Boston Study II.

| | | All N=302 n(%) | No Pain n=96 n(%) | Single Site Pain n=75 n(%) | Multisite Pain n=131 n(%) | P-value† |
|---|---|---|---|---|---|---|
| Age | 70–79 | 35(11.59) | 12(12.50) | 8(10.67) | 15(11.45) | 0.98 |
| | 80–89 | 222(73.51) | 72(75.00) | 50(66.67) | 100(76.34) | |
| | >=90 | 45(14.90) | 12(12.50) | 17(22.67) | 16(12.21) | |
| Gender | Male | 108(35.76) | 41(42.71) | 26(34.67) | 41(31.30) | 0.20 |
| | Female | 194(64.24) | 55(57.29) | 49(65.33) | 90(68.70) | |
| Race | White | 241(79.80) | 79(82.29) | 61(81.33) | 101(77.10) | 0.25 |
| | Black | 46(15.23) | 10(10.42) | 13(17.33) | 23(17.56) | |
| | Other | 15(4.97) | 7(7.29) | 1(1.33) | 7(5.34) | |
| Education | College grad. | 173(57.48) | 57(60.00) | 50(66.67) | 66(50.38) | 0.06 |
| | Not coll. grad. | 128(42.52) | 38(40.00) | 25(33.33) | 65(49.62) | |
| Body mass index | Normal (<25) | 115(38.72) | 44(46.32) | 28(38.36) | 43(33.33) | 0.05 |
| | Over weight (25–29) | 123(41.41) | 35(36.84) | 32(43.84) | 56(43.41) | |
| | Obese (>=30) | 59(19.87) | 16(16.84) | 13(17.81) | 30(23.26) | |
| **Chronic Conditions** | | | | | | |
| Osteoarthritis: | None | 196(70.00) | 86(94.51) | 54(77.14) | 56(47.06) | <0.0001 |
| | Knee only | 31(11.07) | 2(2.20) | 8(11.43) | 21(17.65) | |
| | Hand only | 38(13.57) | 3(3.30) | 8(11.43) | 27(22.69) | |
| | Hand and Knee[a] | 15(5.36) | 0(0) | 0(0) | 15(12.61) | |
| Heart disease | | 123(42.12) | 32(34.78) | 33(45.83) | 58(45.31) | 0.23 |
| Stroke | | 24(7.95) | 7(7.29) | 6(8.00) | 11(8.40) | 0.96 |
| Diabetes | | 36(11.92) | 7(7.29) | 10(18.33) | 19(14.50) | 0.23 |
| Vision (0<vision score<50) | | 57(19.13) | 15(15.79) | 12(16.00) | 30(23.44) | 0.26 |

[a] All participants classified as having hand and knee osteoarthritis reported both hand and knee pain.

† *p*-value for tests (chi-square or fisher's exact test) for overall differences.

**Table 2.**

Single and dual-task gait performance according to pain distribution, 302 older adults, MOBILIZE Boston Study II.

| Number of Pain Sites | | No Pain (n=96) | | Single Site Pain (n=75) | | Multisite Pain (n=131) | |
|---|---|---|---|---|---|---|---|
| **Variables** | | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** |
| Gait Speed (m/sec) | Single-Task | 1.00 | 0.23 | 0.87 | 0.27 | 0.84 | 0.24† |
| | Easy Dual-Task | 0.85 | 0.23 | 0.72 | 0.25 | 0.71 | 0.24† |
| | Hard Dual-Task | 0.78* | 0.24 | 0.68* | 0.25 | 0.67* | 0.24† |
| Stride Length (cm) | Single-Task | 113.33 | 21.34 | 104.05 | 23.50 | 100.18 | 20.47† |
| | Easy Dual-Task | 105.53 | 22.40 | 95.45 | 24.41 | 93.41 | 21.30† |
| | Hard Dual-Task | 102.18* | 23.34 | 92.89* | 24.39 | 90.86* | 21.27† |
| Swing Time (%) | Single-Task | 0.34 | 0.02 | 0.32 | 0.01 | 0.32 | 0.03† |
| | Easy Dual-Task | 0.33 | 0.03 | 0.31 | 0.05 | 0.31 | 0.04† |
| | Hard Dual-Task | 0.32* | 0.04 | 0.30* | 0.06 | 0.30* | 0.04† |
| Double Support Time (%) | Single-Task | 0.33 | 0.05 | 0.37 | 0.10 | 0.37 | 0.07† |
| | Easy Dual-Task | 0.35 | 0.06 | 0.40 | 0.11 | 0.39 | 0.08† |
| | Hard Dual-Task | 0.36* | 0.07 | 0.42* | 0.16 | 0.40* | 0.09† |
| Stride Length Variability (CV)[a] | Single-Task | 4.15 | 2.02 | 4.78 | 2.64 | 4.94 | 2.57† |
| | Easy Dual-Task | 4.98 | 2.46 | 6.38 | 3.51 | 5.94 | 3.16† |
| | Hard Dual-Task | 5.75* | 3.24 | 7.09* | 4.22 | 6.64* | 3.58† |
| Swing Time Variability (CV)[a] | Single-Task | 5.25 | 2.04 | 6.72 | 2.87 | 6.79 | 2.70† |
| | Easy Dual-Task | 7.90 | 4.83 | 9.86 | 4.90 | 9.20 | 4.35† |
| | Hard Dual-Task | 9.07* | 6.09 | 11.35* | 6.76 | 10.65* | 5.78† |

*Test for column trend, according to dual-task difficulty within pain groups (ANOVA) p<0.05

†test for row trend, for linear relationship across pain categories within gait test dual-task conditions (General Linear Model) p<0.05.

[a]CV= coefficient of variation

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**Table 3.**

Relationship between pain distribution and gait performance outcomes under single and dual-task conditions, 292 older adults, MOBILIZE Boston Study II.

| Pain Distribution | Gait Speed β (SE)† | Stride Length β (SE)† | Swing Time % β (SE)† | Double Support Time % β (SE)† | Stride Length Variability (CV) β (SE)† | Swing Time Variability (CV) β (SE)† |
|---|---|---|---|---|---|---|
| Single-Task | | | | | | |
| Single site pain | −0.11(0.03)** | −6.61(2.85)* | −0.05(0.02)** | 0.08(0.03)** | 0.08(0.07) | 0.20(0.05)*** |
| Multisite pain | −0.12(0.03)*** | −9.03(2.61)** | −0.04(0.01)** | 0.08(0.02)** | 0.11(0.06) | 0.24(0.05)*** |
| Easy Dual-Task | | | | | | |
| Single site pain | −0.11(0.03)** | −7.28(2.98)* | −0.07(0.02)** | 0.09(0.03)*** | 0.19(0.06)** | 0.23(0.07)** |
| Multisite pain | −0.09(0.03)** | −7.70(2.72)** | −0.05(0.02)* | 0.08(0.02)*** | 0.11(0.06) | 0.15(0.06)* |
| Hard Dual-Task | | | | | | |
| Single site pain | −0.09(0.03)** | −7.05(2.97)* | −0.08(0.02)** | 0.10(0.03)** | 0.18(0.07)* | 0.22(0.07)** |
| Multisite pain | −0.09(0.03)*** | −7.38(2.72)*** | −0.05(0.02)* | 0.08(0.03)** | 0.11(0.06) | 0.17(0.07)* |

†Multivariable linear regression models with pace gait parameters (gait speed and stride length) and log transformed phase and variability gait parameters (swing time %, double support time %, stride length CV, swing time CV) as dependent variables. The pain distribution groups (single site and multisite pain) are separate predictor variable in the model (“no pain” is regarded as reference for both pain variables). Models adjusted for age in years, sex, years of education, obesity and overweight, psychoactive and analgesic medication use and limited vision.

*Significance of the coefficients for pain groups as predictors of gait parameters $p<0.05$

**$p<0.01$

***$p<0.001$.

**Table 4.**

Dual-task cost (DTC %) according to pain distribution, 302 older adults, MOBILIZE Boston Study II.

| Number of Pain Sites | | No Pain (n=96) | | Single Site Pain (n=75) | | Multisite Pain* (n=131) | |
|---|---|---|---|---|---|---|---|
| **Variables** | | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** |
| Gait Speed (m/sec) | DTC Easy | 15.3 | 10.3 | 18.3 | 10.6 | 15.4 | 11.7 |
| | DTC Hard | 21.7 | 13.9 | 23.0 | 13.1 | 20.9 | 13.5 |
| Stride Length (cm) | DTC Easy | 7.1 | 6.2 | 8.8 | 6.2 | 7.0 | 6.6 |
| | DTC Hard | 10.2 | 8.6 | 11.5 | 7.5 | 9.6 | 7.0 |
| Swing Time (%) | DTC Easy | 3.1 | 4.3 | 5.2 | 6.0 | 4.0 | 5.2 |
| | DTC Hard | 5.2 | 6.4 | 7.8 | 9.1 | 6.2 | 7.2 |
| Double Support Time (%) | DTC Easy | 6.8 | 8.2 | 8.7 | 7.0 | 6.9 | 7.6 |
| | DTC Hard | 11.1 | 13.8 | 13.1 | 13.8 | 10.2 | 10.3 |
| Stride Length Variability (CV)[a] | DTC Easy | 29.3 | 50.5 | 39.6 | 49.7 | 29.7 | 56.0 |
| | DTC Hard | 54.0 | 96.9 | 56.0 | 71.4 | 44.4 | 61.6 |
| Swing Time Variability (CV)[a] | DTC Easy | 56.9 | 109.5 | 51.9 | 50.7 | 43.3 | 79.3 |
| | DTC Hard | 83.5 | 143.4 | 71.6 | 79.4 | 65.9 | 101.0 |

$$DTC\ [\%] = 100\ \times\ \frac{(\mathrm{Sing}le - Task\ Score) - (Dual - Task\ Score)}{\mathrm{Sing}le - Task\ Score}$$ for gait speed, stride length, and swing time (%).

$$DTC\ [\%]\ = 100 \times\ \frac{(Dual - Task\ Score) - (\mathrm{Sing}le - Task\ Score)}{\mathrm{Sing}le - Task\ Score}$$ for double support time (%), stride length variability and swing time variability.

[a]CV= coefficient of variation

*In general linear regression testing for linear trend across pain groups, there was no significant trend in any of the dual-task cost outcomes according to pain distribution.

**Table 5.**

Relationship between pain distribution and Dual-task cost (DTC), 292 older adults, MOBILIZE Boston Study II.

| Pain Distribution | Gait Speed β (SE)† | Stride Length β (SE)† | Swing Time % β (SE)† | Double Support Time % β (SE)† | Stride Length Variability (CV) β (SE)† | Swing Time Variability (CV) β (SE)† |
|---|---|---|---|---|---|---|
| DTC Easy | | | | | | |
| Single site pain | 2.43 (1.71) | 1.41 (0.97) | 1.84 (0.80)* | 1.72 (1.19) | 11.80 (7.79) | −4.51 (13.52) |
| Multisite pain | −0.72 (1.56) | −0.69 (0.89) | 0.37 (0.73) | −0.48 (1.09) | −1.26 (7.12) | −16.32 (12.35) |
| DTC Hard | | | | | | |
| Single site pain | 1.58 (2.08) | 1.41 (1.15) | 2.54 (1.12)* | 2.74 (1.81) | 12.21 (10.98) | −9.84 (17.95) |
| Multisite pain | −0.62 (1.90) | −0.83 (1.05) | 0.50 (1.02) | −0.47 (1.66) | −4.80 (10.04) | −15.99 (16.40) |

$DTC\ [\%] = 100\ \times\ \frac{(\mathrm{Sing}le - Task\ Score) - (Dual - Task\ Score)}{\mathrm{Sing}le - Task\ Score}$ for gait speed, stride length, and swing time (%).

$DTC\ [\%]\ = 100\ \times\ \frac{(Dual - Task\ Score) - (\mathrm{Sing}le - Task\ Score)}{\mathrm{Sing}le - Task\ Score}$ for double support time (%), stride length variability and swing time variability.

†Multivariable linear regression models with DTC variables as dependent variables. The pain distribution categories (single site and multisite pain) are the main predictor variables in the model (“no pain” is regarded as reference). Models adjusted for age in years, sex, years of education, obesity and overweight, psychoactive and analgesic medication use and limited vision.

*Significance of the coefficient for pain as a predictor of dual-task cost, p<0.05.