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Effects of Emotionally Charged Auditory Stimulation on Gait Performance in the Elderly: A Preliminary Study

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Abstract

Objectives—To evaluate the effect of a novel divided attention task—walking under auditory constraints—on gait performance in older adults and to determine whether this effect was moderated by cognitive status.

Design—Validation cohort.

Setting—General community.

Participants—Ambulatory older adults without dementia (N=104).

Interventions—Not applicable.

Main Outcome Measures—In this pilot study, we evaluated walking under auditory constraints in 104 older adults who completed 3 pairs of walking trials on a gait mat under 1 of 3 randomly assigned conditions: 1 pair without auditory stimulation and 2 pairs with emotionally charged auditory stimulation with happy or sad sounds.

Results—The mean age of subjects was 80.6±4.9 years, and 63% (n=66) were women. The mean velocity during normal walking was 97.9±20.6cm/s, and the mean cadence was 105.1±9.9 steps/min. The effect of walking under auditory constraints on gait characteristics was analyzed using a 2-factorial analysis of variance with a 1-between factor (cognitively intact and minimal cognitive impairment groups) and a 1-within factor (type of auditory stimuli). In both happy and sad auditory stimulation trials, cognitively intact older adults (n=96) showed an average increase of 2.68cm/s in gait velocity ($F_{1.86,191.71}$=3.99; P=.02) and an average increase of 2.41 steps/min in cadence ($F_{1.75,180.42}$=10.12; P<.001) as compared with trials without auditory stimulation. In contrast, older adults with minimal cognitive impairment (Blessed test score, 5–10; n=8) showed

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an average reduction of 5.45cm/s in gait velocity ($F_{1.87,190.83}$=5.62; *P*=.005) and an average reduction of 3.88 steps/min in cadence ($F_{1.79,183.10}$=8.21; *P*=.001) under both auditory stimulation conditions. Neither baseline fall history nor performance of activities of daily living accounted for these differences.

Conclusions—Our results provide preliminary evidence of the differentiating effect of emotionally charged auditory stimuli on gait performance in older individuals with minimal cognitive impairment compared with those without minimal cognitive impairment. A divided attention task using emotionally charged auditory stimuli might be able to elicit compensatory improvement in gait performance in cognitively intact older individuals, but lead to decompensation in those with minimal cognitive impairment. Further investigation is needed to compare gait performance under this task to gait on other dual-task paradigms and to separately examine the effect of physiological aging versus cognitive impairment on gait during walking under auditory constraints.

Keywords

Attention; Cognition; Gait; Rehabilitation

Walking is the most commonly reported physical activity in adults.[1–5] Even in young healthy individuals, walking is a complex motor task, similar to catching a moving object, and has been shown to require higher-level cognitive resources, such as executive function.[6] Performing gait analysis during a simultaneous cognitive challenge represents an opportunity to screen elderly individuals who may be at a higher risk of falls and may facilitate their identification before a sentinel event.[7–16]

The walking while talking task is a divided attention task that involves both cognitive and motor components and has been shown to be a reliable and valid test to identify older adults at high risk of multiple adverse outcomes such as falls,[9] frailty, disability, and death.[17,18] Walking while talking replicates what many would consider a “typical” experience for elderly individuals because many individuals may engage in intermittent conversation during ambulatory activity. However, walking during listening to background auditory stimuli is an even more ubiquitous occurrence.[19–24] Walking while listening to background auditory stimuli may be more ecologically valid because it has been shown that older adults have greater difficulty focusing on tasks when distracted by irrelevant information.[25] Acoustically novel stimuli demand attention and produce a distracting effect that can persist for a period of time. In fact, the degree of distraction and its effect on cognitive tasks have been shown to increase with age.[26] The increased distractibility may be partially due to an age-related reduction in processing speed and attention.[27]

However, all auditory stimuli are not the same. Some types of auditory stimuli have been shown to increase function. For example, rhythmic auditory stimulation has been shown to increase gait velocity and stride length via motor entrainment.[28–34] Affective nonverbal vocalizations—laughing and crying—have also been shown to activate the human amygdala regardless of attentive state,[35–39] suggesting that we might be more sensitive to emotionally salient background auditory stimuli. Emotional states have also been shown to have specific effects on gait[40–43]: for example, depressive states decrease ground reaction forces, pleasant emotional states facilitate initiation of forward gait, and anxiety states increase the attentional demand for locomotion.[44] Given the sensitivity of gait parameters to different emotional states, an emotionally salient listening task may be an ideal interference task to challenge the cognitive reserve for mobility and assess fall risk in elderly individuals.

The objective of this preliminary study was to evaluate the effect of a novel divided attention task—walking under auditory constraints—in older adults. A second objective was to determine whether this effect was moderated by cognitive status. We hypothesized that emotionally charged auditory stimuli would elicit compensation (improvement in gait performance) in cognitively intact older adults, but decompensation (decline in gait performance) in older adults with minimal cognitive impairment.

Methods

Subjects

One hundred and five community-residing older adults who were participants in the Latent Mobility Abnormality Study[45,46] were included for the walking under auditory constraints protocol. Informed consent was obtained as per the study protocol approved by the local institutional review board (Division of Cognitive and Motor Aging, Saul R. Korey Department of Neurology, Albert Einstein College of Medicine, Bronx, NY). Inclusion criteria were age ≥70 years and ambulatory status. Participants who were ambulatory but used walking aids were excluded from this sub-study. Exclusion criteria included severe audiovisual loss (unable to follow questions asked in a loud voice or corrected vision <20/200), dementia (as diagnosed by a consensus case conference), and being bed bound or institutionalized.

A detailed neuropsychological test battery was administered, consisting of the Blessed Information-Memory-Concentration Test for general cognition,[47] the Free and Cued Selective Reminding Test[48] for memory, the digit symbol substitution test for cognitive processing,[49] the letter fluency test[50] for executive function, and the digit span test[49] for attention. For the purposes of this study, the Blessed-Information-Memory Concentration Test[47] and the Geriatric Depression Scale[51] were used to test associations between gait and cognitive status.[52] Dementia diagnosis was assigned at consensus case conferences using the *Diagnostic and Statistical Manual*, *Fourth Edition*, criteria[53] and subtyped using established criteria.[45,46] The consensus case conference included a neurologist with geriatric expertise, a psychologist, and a social worker[54] who reviewed all available clinical history, examination, and neuropsychological test findings, as previously described.[55,56] The literature[57,58] supports a high correlation between consensus diagnoses and pathological findings. We excluded 1 subject who met the study criteria for dementia. Of the 105 subjects, 104 (99%) were eligible for this analysis.

At the baseline study visit, all subjects were assessed on their ability to perform 7 activities of daily living (ADL): bathing, dressing, grooming, feeding, toileting, walking around the home, and getting up from a chair. For each task, participants were asked, “At the present time, are you unable to or do you need help from another person to complete the task?” If the response was “yes,” the task was scored as 2. If the response was “no,” participants were asked a follow-up question: "Do you have difficulty in completing the task?" The task was scored as 1 for the response of "yes" and 0 for the response of "no." The disability score was calculated as a sum of the scores from 7 ADLs, with a maximum disability score of 14 (requiring help for all 7 ADLs) and a minimum of 0. Disability was defined as inability or requiring personal assistance in any of the 7 ADLs.[59] The interviewer also assessed fall history over the last 12 months or 1 calendar year during the same baseline study visit. A fall was defined as an event which results in a person coming to rest inadvertently on the ground or other lower level and other than as a consequence of the following: sustaining a violent blow; loss of consciousness; sudden onset of paralysis, as in a stroke; or an epileptic seizure.[60]

Quantitative gait

Gait parameters were obtained using a computerized mat (457.2×90.17×0.63cm) embedded with pressure sensors. Start and stop points were marked by white lines on the floor and included 3ft each for initial acceleration and terminal deceleration for a total length of 6.4m. Subjects were instructed to walk on the mat at their "normal pace" for 2 trials in a quiet, well-lit hallway, wearing comfortable footwear. They were asked to resume walking as soon as they could in case they stopped walking for any reason during the trial. Trial administrators did not advise or encourage subjects during the trials and intervened only in situations in which subject safety was an issue. A trial was not repeated if it was interrupted for any reason. Monitoring devices were not attached to the participants during the test.

The GAITRite walkway system[a] computed quantitative gait parameters on the basis of footfalls recorded. Each trial was 1 walkway in length, and values analyzed were the mean of 2 trials computed automatically by the software. The following variables were obtained from the gait mat: step length, the distance between heel points of the current footfall and previous footfall on the opposite foot; cadence, the number of steps taken in a minute; stride length, the distance between the heel points of 2 consecutive footfalls of the same foot; gait velocity, the distance covered on 2 trials divided by ambulation time; and gait variability, the SD of stride length. Measurements made using this equipment have shown excellent reliability and validity.[46,61]

Auditory trials

Subjects were asked to walk on a computerized walkway twice for each of the 3 randomly assigned conditions: without auditory stimulation, with positively valenced auditory stimulation (happy sounds, the sound of a baby's laughter), and with negatively valenced auditory stimulation (sad sounds, the sound of a woman wailing). Each sound track was approximately 10 seconds in length, lacked any specific rhythm, was begun before the start of walking, and was looped continuously for the duration of the walking trial. At the end of each trial, subjects were asked to rate the emotional valence of the happy or sad sounds on a scale of 1 (no emotion) to 10 (highest emotion) and their feelings in relation to just having heard the happy or sad sounds on a scale of 1 (no feeling) to 10 (highest feeling).

[a]GAITRite; CIR Systems Inc./GAITRite.

Statistical analysis

Two-way factorial analysis of variance with a 1-between factor (cognitively intact and minimal cognitive impairment groups) and a 1-within factor (type of auditory stimuli) (mixed factorial design) was used on each of the gait parameters of interest to determine the effect of walking under auditory constraints. We included the Blessed test score that indicated cognitive impairment as a moderating variable to determine the effect of cognitive status on walking under auditory constraints. Subjects were dichotomized as cognitively intact for a Blessed test score of <5 and as having minimal cognitive impairment for a Blessed test score between 5 and 9.[62] Continuous variables were reported with means and SDs, whereas categorical variables were reported as percentiles.

Because of the sample size imbalance between cognitively intact and minimal cognitive impairment groups, equality of variance assumptions were occasionally violated in the subsequent tests. To account for these discrepancies, statistical corrections were made where appropriate. A Greenhouse-Geisser correction for the effective degrees of freedom was implemented when Mauchly’s test of sphericity was violated, and the subsequent statistics were reported. A Python extension for SPSS version 20[b] called Fuzzy was used to search for 8 cognitively intact subjects matched to the group with minimal cognitive impairment on emotional ratings of both auditory stimuli, and the mixed factorial analysis of variance was performed again on the matched groups. In addition, fall history and performance of ADLs were compared between the 2 groups to further validate the results. SPSS for Mac version 20 was used for all analyses.

Results

The mean age of the 104 subjects was 80.6±4.9 years. Emotionally charged auditory stimulation had a significant effect on gait velocity ($F_{1.86,191.7}$=3.9; P=.02) and cadence ($F_{1.75,180.4}$=10.1; P<.001) for the entire sample.

Subjects were then separated into cognitively intact (n=96) and minimal cognitive impairment (n=8) groups on the basis of their Blessed test scores (1 subject met amnestic mild cognitive impairment syndrome criteria and 7 did not). Demographic information for both groups of subjects is given in table 1. Adding cognitive status as a between-subjects factor showed significant interaction effects with emotionally charged stimuli for both cadence and velocity, but not for walking time, stride length, swing time, or gait variability (table 2). Post hoc pairwise comparisons showed that in both happy and sad auditory stimulation trials, cognitively intact older adults (n=96) showed an average increase of 2.68cm/s in gait velocity ($F_{1.86,\ 191.71}$=3.99; P=.02) (fig 1A) and an average increase of 2.41 steps/min in cadence ($F_{1.75,180.42}$=10.12; P<.001) (fig 1B) as compared with trials without auditory stimulation. In contrast, older adults with minimal cognitive impairment (Blessed test score, 5–10; n=8) showed a reduction of 5.45cm/s in gait velocity ($F_{1.87,190.83}$=5.62; P=.005) and a reduction of 3.88 steps/min in cadence ($F_{1.79,183.10}$=8.21; P=.001) under both auditory stimulation conditions (see fig 1; for additional statistics, see table 3). Additional post hoc tests showed that velocity was significantly different between the cognitively intact

[b]SPSS version 20; IBM Corp.

and minimal cognitive impairment groups under the sad condition (*P*=.043). There were no significant differences between groups at baseline or under the happy condition.

The mean rating scores of emotional valence for happy and sad sounds in subjects with minimal cognitive impairment were significantly higher than those in cognitively intact subjects (happy ratings: $t_{54.5}$=5.97; *P*<.01; sad ratings: t_{102}=2.18; *P*=.03) (fig 2). Subjective feeling scores were also compared between the 2 groups for happy and sad sounds. The mean feeling scores of happy and sad sounds in cognitively intact subjects were 6.7±3.2 and 3.7±3.1, respectively. In contrast, the rating scores in subjects with minimal cognitive impairment were 8.8±2.8 and 7.3±2.6, respectively. The *t* tests showed a near-significant between-group difference in happy feelings (t_{102}=1.8; *P*=.07) and a significant between-group difference in sad feelings (t_{102}=3.1; *P*=.02).

To further validate the main findings in light of group differences in stimuli ratings, subjects with minimal cognitive impairment were matched to an equal number of subjects without cognitive impairment. Congruent with previous analyses (see figs 1 and 2), subjects with minimal cognitive impairment showed contrasting effects compared with the 8 cognitively intact subjects on gait velocity ($F_{2,28}$=3.65; *P*=.039) and cadence ($F_{2,28}$=4.56; *P*=.019), which were reduced with happy and sad sounds.

To assess the validity of differentiation by cognitive status, the 2 groups were also compared for fall history and performance of ADLs. We found no significant differences between the cognitively intact (mean score ±SD, 1.5±0.5) and minimal cognitive impairment (mean score ±SD, 1.6±0.5) groups in falls history over a period of 1 year before the study visit (t_{102}=.54; *P*=.57). There were also no differences between the cognitively intact (1.6±1.6) and minimal cognitive impairment (1.7±1.9) groups in ADL performance (t_{101}=.19; *P*=.84).

Discussion

To our knowledge, this is the first study to characterize gait performance under emotionally charged auditory stimulation conditions in an elderly population. As hypothesized, our findings reveal that gait performance improved in individuals who were cognitively intact when they walked amid a background of emotionally charged auditory sounds. In contrast, gait performance declined under the same conditions in individuals with minimal cognitive impairment.

Gait performance improves under emotionally charged auditory conditions in cognitively intact elderly individuals

Walking parameters have been shown to be influenced by time-evolving auditory stimuli, including television sounds.[30] The effect of rhythmic auditory stimuli on ambulation is also well documented[29,31,33,34,63] and is often ascribed to an “entraining” effect.[34] In our study, older adults with intact cognition were able to improve gait performance (faster velocity and cadence), suggesting effective recruitment of their cognitive resources when challenged. In our study, auditory stimulation represents a distraction. Previous literature[64] supports the idea that older adults compensate for increased distractibility by focusing more strongly on task-relevant stimuli.

Neuroimaging evidence suggests that neural activity associated with cognitive aging is characterized by both age-related increases and decreases in brain activity in specific regions. Failure to activate brain regions typically recruited by younger adults during cognitive tasks usually suggests neurocognitive decline. However, additional neural recruitment during task performance beyond that seen in younger adults is thought to indicate neural compensation.[65–67] Functional imaging studies have revealed that neural compensation results in increased brain activation in the contralateral prefrontal cortex, also known as hemispheric asymmetry reduction in old adults.[68] Thus, low-performing older adults appear to use a similar strategy as do younger adults, but use it inefficiently. In contrast, high-performing older adults appear to counteract age-related neural decline through a plastic reorganization of neurocognitive networks by symmetrical brain activation in functionally relevant neural networks,[66,68] thereby increasing the availability of cognitive resources[69] for task performance.

Gait performance declines under emotionally charged auditory conditions in elderly individuals with minimal cognitive impairment

We found that individuals with minimal cognitive impairment, as suggested by their Blessed test scores,[47,62,70] decreased their gait velocity and cadence when walking under auditory constraints. These findings may be explained by a reduced ability to allocate additional cognitive resources to maintain gait performance when distracted. These findings, therefore, support the decline-compensation hypothesis,[65–67] where an inability to compensate neurally or functionally when challenged uncovers a picture of rapid decline. Even rhythmic auditory stimulation at a comfortable tempo has been shown to produce deleterious effects on gait in those with Alzheimer dementia.[71] Our findings extend this phenomenon to individuals at predementia stages.

It is known that divided attention markedly impairs the ability to regulate gait in individuals with Alzheimer disease.[10,11,14] It appears that performance deficits in aging are due to higher distractibility, in combination with deficits in orienting-reorienting mechanisms.[66] The literature[72] suggests strong associations between age and speed reduction and between cognitive status and speed reduction under dual-task conditions. Neuroimaging reveals a common prefrontoparietal neural network for performing 2 tasks simultaneously or successively.[73,74] It has been suggested that smaller prefrontal area volume may contribute to a slower gait through reduced information processing speeds.[75] Frontal and temporoparietal metabolic impairment on positron emission tomographic scans has been shown to be closely related to the progression of Alzheimer disease.[76] These networks are also thought to explain age-related differences in processing of auditory information. Thus, auditory distraction represents an ecologically valid approach to evaluate cognitive reserve for mobility. The decline in gait velocity during walking under auditory constraints may be an early indication of reduced cognitive reserve.

Significance of using emotionally salient auditory backgrounds

When asked to rate the emotional significance of auditory stimuli, subjects with minimal cognitive impairment consistently rated both happy and sad conditions higher than did subjects without cognitive impairment. This may explain the difference in gait metrics between the 2 groups. The valence scores also provide qualitative support for the effect of auditory emotional stimuli on gait during dual-task conditions. Emotionally charged auditory stimuli activate the amygdala and auditory cortices,[35–38] and affect regulation using cognitive control may be achieved through active cortical suppression of the amygdalar structures.[39] Subjects with minimal cognitive impairment may be unable to suppress amygdalar activation as seen in patients with early dementia,[77–79] resulting in higher emotional ratings. However, when a subsample of cognitively intact subjects with identical emotional ratings was matched to subjects with minimal cognitive impairment in this study, the effect on gait velocity and cadence remained. This suggests that the underlying cognitive impairment, rather than the emotional rating alone, accounts for the effect on gait velocity and cadence.

Study limitations

The main limitation of this study was the small number of subjects with minimal cognitive impairment. A second limitation was that auditory stimuli were not matched against more conventional dual-task paradigms, such as serial 3s or verbal fluency, to compare task effects. Furthermore, although the effects of auditory stimulation on gait metrics were statistically significant, they were not large. In the future, we will incorporate minimal clinical difference analyses and use larger cohorts in longitudinal studies to determine the clinical relevance of the effects of auditory stimulation on gait. In addition, we found differences in velocity and cadence metrics and not in the other measured gait variables. In a recent study, principal component analysis was used to cluster the variables derived from quantitative gait analyses into statistically independent gait domains: rhythm, pace, and variability.[17] Velocity and step length belong to the pace domain; abnormalities in this domain have been shown to predict falls.[17] Cadence, swing time, and step time belong to the variability domain, and abnormalities in this domain have been shown to predict dementia.[17] Thus, the walking under auditory constraints task may differentially affect the control of pacing and variability during gait, and velocity and cadence may be the dominant variables in these domains. However, discrete effects may also be due to the small sample size.

Conclusions

The distinct performance responses to the walking under auditory constraints task in cognitively intact older individuals versus individuals with minimal cognitive impairment provide insights into the nature of cognitive reserve utilization under real-world conditions. Our findings should be replicated in larger samples with a wider spectrum of cognitive impairment and compared with accepted dual-task paradigms. Further exploration is needed to separately examine the effects of physiological aging and cognitive impairment on the relation between auditory stimulation and gait performance.

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List of abbreviations

ADL	activities of daily living

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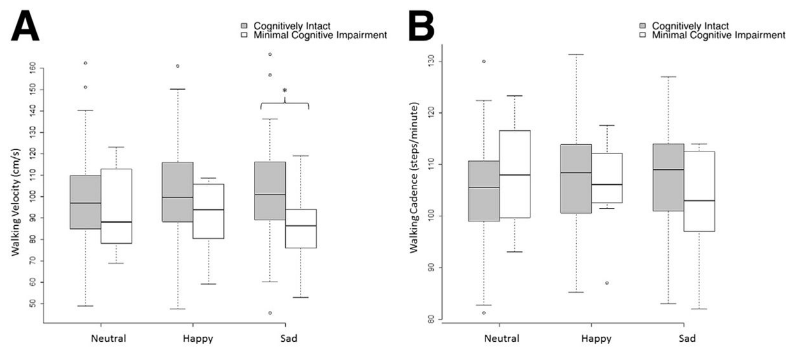

Fig 1.

Effect of walking under auditory constraints on (A) gait velocity and (B) cadence compared between cognitively intact subjects (gray boxplots) and subjects with minimal cognitive impairment (white boxplots). There was a significant interaction effect betw6een the 2 groups (tables 2 and 3). *P<.05.

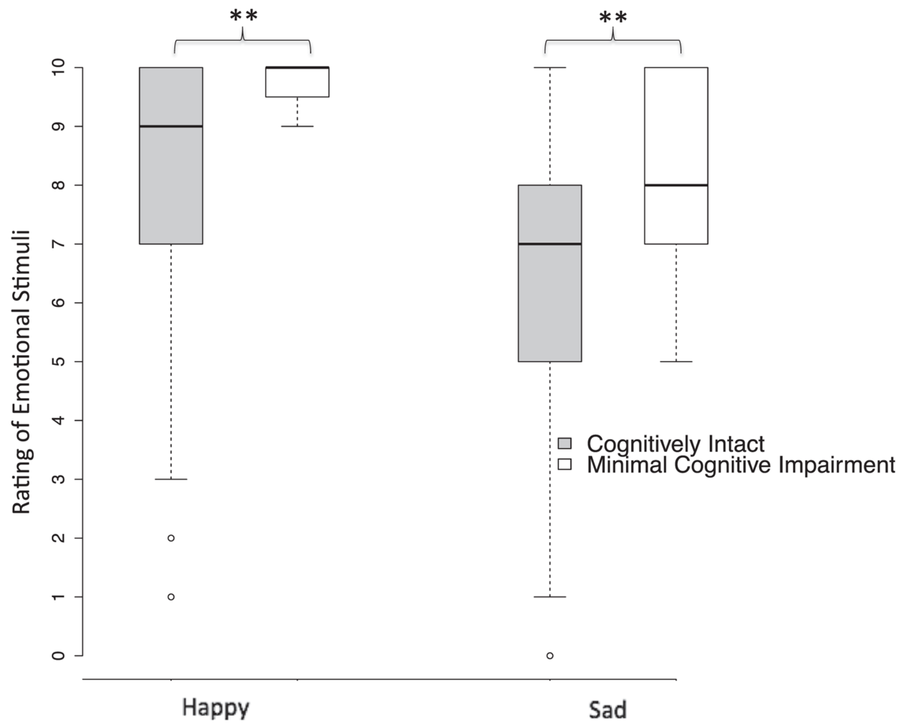

Fig 2.

Rating of emotional stimuli in cognitively intact subjects (gray boxplots) and subjects with minimal cognitive impairment (white boxplots). *P<.01.

Table 1

Demographic statistics for both groups of subjects

Statistic	No Cognitive Impairment (n=96)	Minimal Cognitive Impairment (n=8)
Height (cm)	161.2±9.2	163.4±10.5
Weight (kg)	73.4±14.5	76.3±16
Education (y)	14.9±3	13.3±4.6
Age (y)	80.6±5.1	80.9±4
Geriatric Depression Scale score (range, 0–15)	2.3±2.5	2.3±2.8
Blessed score	1.2±1.3	6.4±1.2
Sex: female	60 (62.5)	6 (75)

NOTE. Values are mean ±SD or as n (%).

Table 2

Gait parameters for both groups of subjects

Gait Variables	No Cognitive Impairment (n=96)	Minimal Cognitive Impairment (n=8)
Velocity		
Neutral	98.3±2.1	93.8±7.29
Happy	101±2.07	91±7.19
Sad	100.8±2.05	85.6±7.1
Cadence		
Neutral	104.8±1	108.1±3.5
Happy	107.5±1	105.8±3.5
Sad	107±1.1	102.7±3.7

NOTE. Values are mean ±SE.

Table 3

Gait variables and their interaction with cognitive status

Gait Variable	Interaction Effect
Time	$F_{1.43,145.59}$=.69; *P*=.46
Velocity	$F_{1.87,190.8}$=5.6; *P*=.005
Cadence	$F_{1.79,183.1}$=8.21; *P*=.001
Stride length	$F_{2,204}$=2.21; *P*=.11
Swing time	$F_{1.87,191.13}$=1.18; *P*=.31
Gait variability (stride length SD)	$F_{2,204}$=.61; *P*=.55