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Reconceptualizing balance: attributes associated with balance performance

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A B S T R A C T

Balance tests are commonly used to screen for impairments that put older adults at risk for falls. The purpose of this study was to determine the attributes that were associated with balance performance as measured by the Frailty and Injuries: Cooperative Studies of Intervention Techniques (FICSIT) balance test. This study was a cross-sectional secondary analysis of baseline data from a longitudinal cohort study, the Boston Rehabilitative Impairment Study of the Elderly (Boston RISE). Boston RISE was performed in an outpatient rehabilitation research center and evaluated Boston area primary care patients aged 65 to 96 (N = 364) with self-reported difficulty or task-modification climbing a flight of stairs or walking 1/2 of a mile. The outcome measure was standing balance as measured by the FICSIT-4 balance assessment. Other measures included: self-efficacy, pain, depression, executive function, vision, sensory loss, reaction time, kyphosis, leg range of motion, trunk extensor muscle endurance, leg strength and leg velocity at peak power. Participants were 67% female, had an average age of 76.5 (±7.0) years, an average of 4.1 (±2.0) chronic conditions, and an average FICSIT-4 score of 6.7 (±2.2) out of 9. After adjusting for age and gender, attributes significantly associated with balance performance were falls self-efficacy, trunk extensor muscle endurance, sensory loss, and leg velocity at peak power. FICSIT-4 balance performance is associated with a number of behavioral and physiologic attributes, many of which are amenable to rehabilitative treatment. Our findings support a consideration of balance as multidimensional activity as proposed by the current *International Classification of Functioning, Disability, and Health* (ICF) model.

1. Introduction

Balance is a skill that, when deficient, leads to falls and fall-related injuries such as hip fractures (Berg et al., 1992a; Speechley and Tinetti, 1991). Clinical tests of balance are commonly used to screen older adults who are at risk for falls and hip fractures (Rubenstein, 2006; VanSwearingen and Brach, 2001). Conceptually, balance tests have been developed as a way to screen for the presence of balance impairments (Bean et al., 2008; Jette, 1997). However, within the most current conceptual paradigms of physical function, the World Health Organization's *International Classification of Functioning, Disability, and Health* (ICF), *impairments* are deficiencies in the function of a single body system or the anatomical parts of a single body structure. *Activity* is a higher order concept, and represents the execution of a task relating to the interaction of multiple body systems (Jette, 2006). Operationally, most clinical balance tests involve the performance of multiple tasks and thus conceptually, the maintenance of balance is better characterized as an activity (Lin and Whitney, 2012; Salter et al., 2005).

A number of studies have sought to determine which impairments are most associated with clinical assessments of activities, including gait speed and general physical performance (Bean et al., 2008; Mayson et al., 2008; Rantanen et al., 2001; Sanders et al., 2012). Reviews, such as Pasma et al. (2014), have called for further research to be done to determine attributes underlying balance while standing. There is ample evidence within separate investigations identifying body systems such as mental function [ie. self-efficacy] (Myers et al., 1996, 1998), sensory function [ie. peripheral sensation] (Meyer et al.,

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2004; Richardson et al., 1996; Strotmeyer et al., 2008), and neuromuscular function [ie. strength (Suri et al., 2011) and velocity] (Bean et al., 2010; Mayson et al., 2008) as being relevant to balance performance. In our review of this literature, however, we identified inconsistencies in the categorization of static balance as performance of an activity, as it is categorized within the current ICF paradigm (Allet et al., 2012; Desai et al., 2010; Pardasaney et al., 2012). Furthermore, no study has evaluated the relative contribution of these different attributes (mental function, behavioral factors, sensory function, and neuromuscular function).

Most static clinical balance tests such as the FICSIT-4 or the balance component of the Short Physical Performance Battery (SPPB) are quite suitable for clinical settings because they can be completed easily and quickly (i.e., <5 min). The FICSIT-4 was developed as part of the Frailty and Injuries: Cooperative Studies of Intervention Techniques (FICSIT trials) (Rossiter-Fornoff et al., 1995). It includes all three stances from the SPPB balance component as well as the more complex unipedal stance to evaluate individuals across a broader range of balance performance. While the FICSIT-4 might be considered a potentially useful clinical tool, it is not known which attributes determine performance. From a rehabilitative perspective, it would be important to understand the body system categories underlying performance in order to know which attributes should be targeted in rehabilitative care.

We hypothesized not only that attributes from multiple body systems identified by the ICF framework (mental functions, sensory, and neuromuscular) combine to determine balance performance as measured by the FICSIT-4, but also that consequently the ICF framework has correctly categorized balance as an activity. Related to this goal, we sought to identify the attributes underlying balance performance in order to understand potential body systems to be targeted through rehabilitative care.

2. Methods

We performed a secondary cross-sectional analysis of baseline assessment information from the Boston Rehabilitative Impairment Study of the Elderly (Boston RISE), a cohort study of older primary care patients (N = 430) living in the greater Boston area. All methods and procedures were approved by the Spaulding Rehabilitation Hospital Institutional Review Board. A detailed description of the Boston RISE protocol is published elsewhere (Holt et al., 2013).

Participants were adults aged ≥65 years receiving primary care at one of two large academic medical centers in Boston—Massachusetts General Hospital (MGH) or Brigham and Women's Hospital (BWH). Initial eligibility was defined as self-reported difficulty or task modification either climbing a flight of stairs or walking a 1/2 mile. Exclusion criteria included inability to communicate in English, presence of a terminal disease, major surgery or myocardial infarction in the past 6 months, planned major surgery, or major medical problems interfering with safe and successful testing. A final eligibility screen excluded individuals with moderate to severe cognitive impairment as measured by a Mini-Mental State Exam (MMSE) score of less than 18, or presence of severe mobility limitations as measured by a score of less than 4 on the Short Physical Performance Battery (SPPB) (Holt et al., 2013). The SPPB is a physical performance measure that is predictive of disability and mortality and has three components: standing balance, gait speed, and chair stands. Each section has a maximum score of 4 points, summing to the maximum score of 12, which represents lower body mobility performance. We included only those Boston RISE participants (N = 364) that completed all of the measures utilized in this ancillary study at baseline.

2.1. Outcome measure

The FICSIT-4 balance test involves asking participants to maintain four progressively difficult foot positions for 10 s each. For the first position (side by side stance), the participant stands with their feet together, side-by-side and touching. The second position (semi-tandem stance) involves the participant standing with the side of one heel touching the big toe of the other foot. For this position, the participant was able to pick whichever foot was more comfortable to place in front. In the third balance position (tandem stance), participants were asked to stand with one foot directly in front of the other, the heel of one foot touching the tip of the big toe of the other foot. Again, participants were allowed to choose which foot was placed in front. For the final position (the unipedal stance), participants were asked to stand on one foot for 10 s (Rossiter-Fornoff et al., 1995). Within the unipedal stance position, if the participant did not successfully maintain the position for even 1 s, no further attempts were allowed. If the participant maintained the position for 2–9 s, a second attempt was allotted. If the second attempt also failed, the test was considered terminated. They could choose to stand on whichever foot they found most comfortable. Participants were instructed to avoid resting the non-weight bearing foot on the weight bearing leg.

For scoring the side by side, semi-tandem, and tandem positions, participants received 0 points for holding the position <1 s, 1 point for holding from 1 s to <10 s, and 2 points for completing 10 s in the position. For the unipedal stance, participants received 0 points for holding the position for <1 s, 1 point for holding from 1 s to <5 s, 2 points for holding from 5 s to <10 s, and 3 points for completing 10 s in the position. The sum of the 4 components yields the maximum FICSIT-4 score of 9 points.

2.2. Mental functions

Executive function was assessed using the Trail Making Test (TMT) (Mirelman et al.). The TMT consists of two components: a task that is highly dependent on processing speed (Trail A), and a task that is more dependent on executive function, but is also influenced by processing speed (Trail B). To best isolate the unique contribution of executive function, we used the standard approach of calculating the difference between the Trail B and Trail A results (Lowry et al., 2012; Salthouse, 2011). Self-efficacy, or balance confidence, was measured using the Activities-Specific Balance Confidence Scale (Powell and Myers, 1995). Symptoms of depression were defined using a clinical cut-point of 5 or greater on the Patient Health Questionnaire (PHQ-9) (Kroenke and Spitzer, 2002).

2.3. Sensory body systems

Pain severity was assessed using the Pain Severity Subscale of the Brief Pain Inventory. This measure averages four pain ratings: the least pain, worst pain, average pain in the previous week, and current pain (Cleeland and Ryan, 1994). Sensory loss was assessed using the Semmes Weinstein Monofilament Test, using 4.17 g and 5.07 g monofilaments (Olaleye et al., 2001). For each foot, the assessor began by applying the 4.17 g monofilament to the dorsum of the great toe four times at randomly varying intervals. Participants were instructed to say “yes” each time they felt the monofilament. If they reported that they felt at least three accurately, the test was completed for that side. Otherwise, the procedure was repeated using the 5.07 g monofilament. Sensory loss was defined as feeling less than three touches with the 4.17 monofilament and less than three touches with the 5.07 monofilament on one or both sides. Visual acuity was measured using a Snellen chart with a vision score of 20/50 or worse being defined as vision impairment (Vitale et al., 2006).

2.4. Neuromuscular body systems

Reaction time was measured using methods and a device developed by Lord et al. (2003). Participants were asked to click a computer mouse as fast as possible in response to illumination of a red light connected to the device. The participant was given five practice trials and then the next ten response times were collected. An electronic timer measured the time it took for the participant to click the mouse in response to the light stimulus. Kyphosis was measured using a flexicurve ruler. An index was derived by dividing the measured curve length in centimeters by the curve height in centimeters as previously described (Milne and Williamson, 1983). Rapid leg coordination was assessed in each leg using the heel-to-shin test. Participants were seated in a chair with their arms crossed over their chest. They were instructed to lift one foot off of the floor, tap the lateral aspect of the opposite leg 4 in. below the patella using their heel, and then return the foot to the floor. They were asked to repeat this movement as quickly as possible ten times in a row. Rapid leg coordination was reported as the fastest time to complete the ten repetitions regardless of side.

Trunk flexor muscle endurance was measured with the participant lying supine on an adjustable table positioned at 45° from vertical with a foam pad placed between the participant's back and the table. The participant's legs were bent so that their feet were flat on the table and they were fixed into position. The participant was asked to cross their arms across their chest and to lift their upper body off of the table just enough so that the foam pad could be removed. They were asked to maintain that 45 degree position as long as possible with their entire back off of the table. The test was terminated when the participant could no longer maintain the unsupported position and their back touched the table. Time was recorded in seconds. Trunk extensor muscle endurance was measured using the commercially available exam table seen in Fig. 1. The table was positioned at a 45-degree angle from the horizontal plane. The table is hinged so that the upper portion of the table could be fixed at a horizontal position. The table also had an adjustable footplate, which was adjusted to position the participant's hips over the hinged portion of the table. The participant was in a prone position with their feet on the footplate, their thighs resting on the lower body segment of the table, and their elbows supporting their upper body on the horizontal upper body segment. The participant was then instructed to cross their arms over their chest and raise their upper body off of the table and into alignment with their lower body (at a 45 degree angle from the horizontal). The participant was asked to maintain this position for as long as possible with arms across their chest. The test was terminated when the participant was no longer able to maintain the unsupported position. Time was recorded in seconds.

Knee flexion and extension were measured with the participant lying flat on a table. For knee extension, a goniometer was centered over the lateral femoral epicondyle with arms directed towards the sagittal midpoint of the thigh and foreleg. The participant was asked to fully extend their leg, pressing the back of their knee against the table. For knee flexion, the goniometer placement was identical and the participant was asked to actively maximally flex their knee. Hip position was kept at 90° during flexion. Ankle range of motion loss was defined as a dorsiflexion less than 90° or plantarflexion less than 110° on either foot.

Fig. 1. The commercially available exam table used for the trunk extension endurance assessment. A participant is seen appropriately performing the task.

Leg strength and leg velocity at peak power were measured using the Keiser A420 Pneumatic Leg Press (Keiser Co.; Fresno, CA) as previously described (Mayson et al., 2008). The one repetition maximum (1RM) and maximum leg power were determined using the protocol described by Cuoco et al. (2004). Leg velocity was derived from maximum leg power. The Keiser A420 graphical output was inspected and the peak values for strength and power were determined for each leg. Leg velocity was derived by dividing the peak power by the force recorded at peak power (Velocity = power / force). Leg strength asymmetry was calculated as the quotient of the 1RM on the stronger side over the 1RM on the weaker side.

2.5. Adjustment variables

Baseline adjustment variables considered for inclusion in our models were age, sex, and body mass index (BMI). Weight status was defined by standard cut points: overweight (BMI $\geq$ 25 kg/m^2 to <30 kg/m^2) and obese (BMI $\geq$ 30 kg/m^2) (LamonFava et al., 1996). The number of active medical conditions was collected using the comorbidity questionnaire developed by Sangha et al. (2003).

2.6. Statistical analysis

All statistical analyses were performed with SAS software, version 9.2 (SAS Institute, Inc., Cary, NC). Descriptive statistics were calculated, including frequencies and percentages for categorical variables and mean and standard deviations for continuous variables. Descriptive characteristics were also calculated for the 66 Boston RISE participants that were excluded from the analysis to identify if they differed meaningfully from the participants included in the analyses. Leg strength was normalized by body weight in kilograms. Correlations were evaluated between all physiologic attributes and adjustment variables to evaluate for co-linearity ($r > 0.40$). Multivariable linear regressions were constructed using a manual, backwards elimination process as advocated by Sun et al. (1996). Briefly, an initial model was run with all the included variables. The attribute with the largest *p-value* was removed and the remaining attributes were run in a new model. This process was repeated until all remaining variables were statistically significant. The final model was evaluated for inappropriately influential observations using the DFFITS and DFBETA influential statistical calculations in SAS (SAS Institute Inc., 2009). Individuals with potentially influential values were identified using a cut-off of 2 as suggested by Belsley et al. (1980). If their exclusion did not materially alter the model, they were included within the final model.

3. Results

Baseline characteristics, and the mental, sensory, and neuromuscular body systems measured are reported in Table 1. Associations between individual attributes and the FICSIT-4 balance score are reported in Table 2. All attributes demonstrated significant associations with the FICSIT-4 with the exception of sex, weight status, PHQ-9, kyphosis, and leg strength asymmetry. Variables that described relatively large amounts of variance (>10%) in FICSIT-4 balance performance were age ($R^2 = 0.14$), self-efficacy ($R^2 = 0.13$), and trunk extensor muscle endurance ($R^2 = 0.18$).

Table 3 shows the factors that were associated with the balance score in the multivariable adjustment. This final set of characteristics and attributes described 37% of the variance in balance performance.

Table 1
Baseline characteristics of the Boston RISE cohort (N = 364).

Category	Characteristic		Mean (SD) or frequency (%)	Range
Demographics	Age (y)		76.5 ± 7.0	65–94
	Women		246 (68%)	n/a
	BMI (kg/m^2)		29.2 ± 5.8	18.4–55.7
	Race	White	297 (82%)	n/a
		Black	43 (12%)	n/a
		Other	24 (6%)	n/a
	Attended college		196 (54%)	n/a
	Comorbidity		4.0 ± 2.0	0–11
Mental functions	PHQ-9 (≥5)		18 (5%)	n/a
	ABC (0–100)		76.9 ± 17	8–100
		<50	26 (7%)	n/a
		50–80	152 (42%)	n/a
		>80	186 (51%)	n/a
	Trail B time–Trail A time (s)		74.3 ± 48.7	−2.9–266.7
Sensory functions	BPI (1–10)		2.5 ± 1.8	0–9.75
	Sensory loss		109 (30%)	n/a
	Visual impairment		18 (5%)	n/a
Neuromuscular functions	FICSIT-4 balance (0–9)		6.9 ± 2.1	1–9
	Reaction time (ms)		248.4 ± 51.2	172.1–648.4.4
	Kyphosis index (cm)		10.4 ± 3.1	3.3–22.4
	Rapid leg coordination (s)		11.1 ± 3.0	5.5–28.3
	Trunk extension endurance (s)		95.4 ± 58.6	0–150
	Knee flexion (degrees)		125.5 ± 12.7	69.0–149.0
	Knee extension (degrees)		7.6 ± 7.8	−5.0–25.0
	Loss of ankle ROM		99 (27%)	n/a
	Leg strength (N/kg)		9.5 ± 2.5	3.1–20.3
	Leg strength asymmetry (ratio of stronger side to weaker side)		1.2 ± 0.3	1–4.3
	Leg velocity at peak power (m/s)		1.0 ± 0.3	0.2–1.9

BPI = Brief Pain Inventory (Severity); PHQ-9 = Patient Health Questionnaire; ABC = Activities-Specific Balance Confidence Scale; ROM = Range of Motion.

After adjustment (adjustment variables—age and sex), falls self-efficacy, trunk extensor muscle endurance, sensory loss, and leg velocity were found to be significantly associated with static balance performance as measured by the FICSIT-4 balance scale.

A comparison was conducted between those excluded and those included in the final model. This analysis revealed that those excluded had significantly lower body mass indexes, a higher number of chronic conditions, and lower self-efficacy scores.

4. Discussion

The major finding of our study is that multiple ICF body system attributes including mental (self-efficacy), sensory, and neuromuscular (trunk extensor muscle endurance and leg velocity) were independently associated with FICSIT-4 balance performance. Our study's aim was not only to identify the body systems that were associated with balance performance, but also to confirm that this clinical test of balance (FICSIT-4) is best characterized as a measure of activity as opposed to a test representing a single body system according to the ICF disablement framework (Jette, 1997, 2006). The current findings support the hypothesis that attributes from multiple body systems determine balance performance as measured by the FICSIT-4, and highlight the point that poor performance in maintaining a standing position is viewed correctly within the ICF framework as an activity restriction and not as a body system impairment.

The observed associations of body systems within this study are well justified mechanistically. Sensory function, measured as peripheral sensation and proprioceptive feedback from the lower extremities, contributes to one's ability to maintain balance (Meyer et al., 2004; Richardson et al., 1996; Strotmeyer et al., 2008). A deficit in either of these feedback mechanisms could conceivably contribute to difficulty with static balance. The trunk muscles are used to maintain an upright position necessary for sitting, standing, ambulating, and performing activities of daily living. The association of trunk extensor muscle endurance with balance performance has been demonstrated within other studies. For example, in a report evaluating the Berg Balance Scale, changes in trunk extensor muscle endurance in response to rehabilitative exercises were predictive of clinically meaningful improvements in Berg Balance Performance (Suri et al., 2011). Additionally, the ability to generate a force with sufficient velocity to make rapid corrections in body position and prevent a fall can clinically account for the association between leg velocity and balance while standing (Bean et al., 2010; Mayson et al., 2008; Son et al., 2009). Our findings using the FICSIT-4, which includes the three balance tasks from the SPPB, are consistent with previous findings supporting the association between leg velocity and SPPB performance (Bean et al., 2008, 2011). Leg velocity and trunk muscle extensor

Table 2
Bivariate linear regression models of associations between patient characteristics and balance performance (N = 364).

Category	Parameter	Estimate (SE)	R^2	*p-Value*
Demographics	Age	−0.114 (0.01)	0.14	<0.001
	Sex	−0.465 (0.24)	0.01	0.049
	Overweight	−0.012 (0.23)	0.00	0.959
	Obese	−0.027 (0.23)	0.00	0.909
	Attended college	0.369 (0.22)	0.01	0.098
Attributes	Comorbidity	−0.156 (0.06)	0.02	0.005
	BPI (severity)	−0.094 (0.06)	0.01	0.123
	PHQ-9	−0.025 (0.51)	0.00	0.962
	ABC	0.046 (0.01)	0.13	<0.001
	Trail B–Trail A	−0.007 (0.00)	0.03	0.005
	Reaction time	−0.007 (0.00)	0.03	<0.001
	Kyphosis	−0.072 (0.04)	0.01	0.044
	Rapid leg coordination	−0.980 (0.04)	0.03	0.003
	Trunk extension endurance	0.015 (0.00)	0.18	<0.001
	Sensory loss	−1.10 (0.24)	0.06	<0.001
	Knee flexion ROM	0.025 (0.01)	0.02	0.004
	Knee extension ROM	0.013 (0.02)	0.00	0.478
	Loss of ankle ROM	−1.105 (0.24)	0.05	<0.001
	Leg strength	0.218 (0.04)	0.07	<0.001
	Leg strength asymmetry	−0.420 (0.38)	0.00	0.264
	Leg velocity at peak power	1.926 (0.42)	0.05	<0.001
	Visual impairment	−1.489 (0.51)	0.02	0.003

BPI = Brief Pain Inventory (Severity); PHQ-9 = Patient Health Questionnaire; ABC = Activities-Specific Balance Confidence Scale; ROM = Range of Motion.

Table 3
Final multivariate linear regression model predicting static balance as measured by the FICSIT-4 balance test (N = 364; R^2 = 0.3659).

Predictor	Parameter estimate (SE)	*p-Value*	Standardized Estimate
Age	−0.070 (0.01)	<0.001	−0.23
Sex	−0.764 (0.22)	<0.001	−0.17
ABC	0.025 (0.01)	<0.001	0.20
Trunk extension endurance	0.011 (0.01)	<0.001	0.30
Sensory loss	−0.587 (0.20)	0.005	−0.13
Leg velocity	1.051 (0.41)	0.01	0.13

Final model was determined using a manual, backwards elimination (Sun et al., 1996). ABC = Activities-Specific Balance Confidence Scale.

endurance are categorized within the ICF as neuromuscular functions. We evaluated the mental function of self-efficacy with regard to balance and mobility tasks and quantified it using the Activities-Specific Balance Confidence Scale. Its association with balance performance has been previously reported in studies evaluating falls and the Timed Up and Go as outcomes (Myers et al., 1996, 1998; Powell and Myers, 1995).

While these attributes have all been previously associated with other physical performance tests, to our knowledge, this is the first study to extensively evaluate a clinical standing balance test within the context of the ICF model. Other studies have examined attributes associated with balance and mobility tasks, but this investigation has a more extensive evaluation of clinically relevant attributes associated with performance and is the first to examine a broad range of factors in relation to the FICSIT-4 performance. Also, it is important to acknowledge that the FICSIT-4 balance test is very similar technically to the balance components of the Short Physical Performance Battery and the balance component of the Health ABC performance battery (Guralnik et al., 1994; Simonsick et al., 2001). Thus, it is reasonable to consider that our findings will have relevance to the performance of the balance components of these tests as well.

The FICSIT-4 offers certain clinical advantages. It is relatively quick to perform (<5 min) and requires only a small space, making it a potentially useful screening tool for balance limitations within primary care settings. Other clinical balance tests such as the Berg Balance Scale (Berg et al., 1992b), Performance Oriented Mobility Assessment (Tinetti, 1986), or Dynamic Gait Index (Shumway-Cook et al., 1997) are advantageous in their ability to provide broad assessment, but they are less feasible clinically since they take much longer to perform. Our findings can also direct rehabilitative clinicians towards body systems that underlie balance performance (e.g., self-efficacy, trunk extensor muscle endurance, leg strength) and should be targeted within care. Although our investigation has focused on balance performance, it has not focused on falls. The relevance of FICSIT-4 performance and its underlying attributes to falls among primary care patients has yet to be comprehensively evaluated and thus our findings should be viewed in the appropriate context. Further research is needed to demonstrate whether a rehabilitation program targeting deficits in the balance-related attributes we have identified will lead to better balance and reduction in fall risk.

There are limitations to our study. We performed a secondary cross-sectional analysis of baseline data, so this study lacks a temporal basis needed for any causal relationship. Only a single static balance outcome measure was used and there may be other measures of balance that, if evaluated, would elicit different attributes. Also, there may be other factors that contribute to poor balance while standing that were not assessed in this investigation, such as vestibular impairments. The Boston RISE study included, the monofilament test, a measure of light touch, as a measure of sensory loss. We recognize that other sensory modalities not included within Boston RISE, such as ankle proprioception may be relevant to static balance.

However, this study has a number of strengths. Our baseline analysis of an extensive impairment-based assessment evaluated the association between a wide variety of body systems. The Boston RISE study design is a cohort study of primary care patients and thus provides clinical relevance to patients who may be referred for rehabilitative care.

5. Conclusion

In conclusion, this study was conceived using the ICF framework and identified multiple body systems relevant to static balance performance as measured by the FICSIT-4. Our findings suggest that self-efficacy, sensory loss, trunk extensor muscle endurance, and leg velocity are attributes that are relevant to FICSIT-4 performance. These results support the ICF categorization of balance problems as an activity limitation as opposed to a single body system impairment.

Conflict of interest

The authors have no conflicts of interests.

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