

Test-Retest Reliability and Response Stability of Gaze Stabilization, Postural Sway, and Dynamic Balance Tests in Persons with Multiple Sclerosis and Controls

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Background: Psychometric properties of tests that assess the angular vestibulo-ocular reflex (aVOR) and vestibulospinal reflex function are currently unknown. This study investigated the test-retest reliability and response stability of gaze stabilization, postural sway, and dynamic balance measures in persons with multiple sclerosis (MS) and controls.

Methods: Nineteen adults with MS and 14 controls performed passive horizontal head impulses, quiet standing, and dynamic balance tests on two separate occasions. Gaze stabilization measures included aVOR gain, number of compensatory saccades (CSs) per head rotation, CS latency, and gaze position error. Postural sway included sway amplitude and total sway path. Dynamic balance measure included the Functional Gait Assessment. Intraclass correlation coefficient, standard error of measurement (SEM, SEM%), and minimal detectable difference at 95% confidence level were calculated.

Results: Test-retest reliability for aVOR gain, CSs per head rotation, and gaze position error was moderate and for each postural sway and dynamic balance measure was good. Low error (SEM, SEM%) for aVOR gain, CS latency, postural sway, and dynamic balance variables and low minimal detectable difference values for aVOR gain and Functional Gait Assessment scores were seen, suggestive of acceptable response stability.

Conclusions: These results support the utility of some of the gaze and postural measures for examination and treatment efficacy purposes in people with MS. *Int J MS Care.* 2020;22:136-142.

Balance disorders are frequent in persons with multiple sclerosis (MS),¹ which may result in falls, comorbidities, decreased physical activity, and impaired quality of life.^{2,3} Imbalance and a high incidence of falls (>50%)^{4,5} form an important health and societal participation concern in persons with MS

due to the associated restrictions in activities of daily living, the injury-related financial costs, and the increased risk of mortality.^{2,3,6} Gaze and postural instabilities have been associated with balance impairments and increased fall risk in older individuals and in people with various neurologic disorders.^{2,7,8} However, these factors are not

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frequently examined in persons with MS during routine clinical practice, demonstrating the need for comprehensive balance assessments when investigating underlying visual, vestibular, or proprioceptive deficiencies. Moreover, the measurement properties of various gaze and postural assessments have not been well-studied in persons with MS, which may further hinder their use by clinical providers in practice.

Gaze stabilization during head movements is a function of the vestibulo-ocular reflex (VOR) and other oculomotor strategies that generate compensatory eye movements to maintain visual stability of a target.^{9,10} Accurate perception and integration of the vestibulo-ocular and vestibulospinal sensations is required to maintain gaze and postural stability during daily movements.⁹ Recently, the video head impulse test (vHIT) has been used to assess gaze stabilization,¹¹ and although the measurement accuracy of vHIT has been established in people with peripheral vestibular loss,¹¹⁻¹³ there are limited data available on its reliability in individuals with central neurologic disorders such as MS or in healthy individuals.

Postural instability is frequently examined by standing postural sway and clinical balance measures. Standing postural sway measures use center of pressure (COP)-based findings on a force platform.¹⁴ Impairments in standing postural sway have been associated with balance and gait impairments^{15,16} and are identified as important factors in the relearning of independent standing and walking abilities.¹⁷ Still, the reliability of static posturographic tests and related spatial domain parameters (amplitude, sway path) are less examined in people with MS.^{18,19} Clinical balance measures, on the other hand, include a variety of performance-based tests, such as reaching, timed walking, and stair climbing tests. One such measure is the Dynamic Gait Index, which has previously been studied in people with MS²⁰⁻²²; however, the reliability of a modified version, the Functional Gait Assessment (FGA), is currently unknown in persons with MS. Because low scores on the FGA have been associated with fall risk and balance deficits in people with vestibular disorders,²³ there is a need to examine its reliability in people with MS who frequently present with balance dysfunction.

Identification of reliability and response stability are critical to detect true test score changes between two sessions beyond that attributable to measurement error. Because the psychometric properties of instrumented gaze stabilization (vHIT), postural sway (COP), and

clinical dynamic balance (FGA) measures are not distinctly established in persons with MS, there is a need to assess their reliability and response stability to confidently document gaze and postural performance in this population. Therefore, to support the use of these outcome measures for examination and treatment purposes, we aimed to investigate the test-retest reliability and the stability of repeated responses for gaze stabilization, postural sway, and dynamic balance measures in people with MS and in age-matched controls. We hypothesized that these measures would demonstrate at least moderate reliability and acceptable response stability in people with MS and controls.

Methods

Participants

Thirty-nine persons with MS recruited from local neurologist practices and support groups were screened (Figure S1, published in the online version of this article at ijmsc.org). Age-matched neurologically healthy controls were recruited from the community. The data presented for this study are part of a larger trial⁸ in which the sample size was determined from previously observed effect sizes for between-group differences in angular VOR (aVOR) gain using vHIT.¹³ The aVOR is an involuntary eye movement reflex that stabilizes retinal images during angular head perturbations to maintain clear vision, and the aVOR gain is typically determined by the ratio of peak eye velocity to peak head velocity during head perturbations. Selection criteria for people with MS were as follows: 18 years or older; confirmed MS diagnosis; able to stand for at least 30 seconds without support; Expanded Disability Status Scale score of 6.5 or less; fall risk established by meeting one of four criteria (≥ 2 retrospective falls per year, Activities-Specific Balance Confidence Scale score < 70 , Berg Balance Scale score < 44 , or Dizziness Handicap Inventory score > 59)²⁰; no history of exacerbations in the previous 3 months; no history of other peripheral or central nervous system injury or neuro-otologic condition besides MS; absence of internuclear ophthalmoparesis or ophthalmoplegia; and absence of other orthopedic, cognitive, medical, or surgical limitations that may limit their study participation.

Study Procedures

Participants who met the inclusion criteria signed an institutional review board-approved informed consent form and provided the medical, MS-related, and fall history via personal interviews. Thereafter, the fall risk assessments to identify persons with MS who met any one of the four aforementioned fall risk criteria were conducted. Regarding persons with MS with fall risk, we excluded those with peripheral vestibular pathologic abnormalities identified by a clinical vestibular examination. In persons with MS identified as a fall-risk, we excluded those with peripheral vestibular pathologies by a clinical vestibular examination comprising oculomotor range of motion, bedside HIT, VOR cancellation test, saccades, and

test of skew.⁹ Peripheral vestibular pathologic abnormalities were screened for using an infrared video goggles system, and nystagmus at rest, nystagmus during benign positional vertigo tests, and head-shake nystagmus examinations. The consented participants subsequently underwent a physical therapist (H.G.)-administered neurologic examination (Expanded Disability Status Scale).²⁴ The gaze stabilization, standing postural sway, and dynamic balance measurements were then conducted on a single day, followed by a repeated assessment on a different day. The assessment days were separated by at least 2 days (Figure S1) and were conducted by the same assessor (H.G.). The fall risk screening; clinical vestibular, neurologic, and instrumented gaze; and balance evaluations were performed by a qualified trained assessor with a physical therapy license and more than 4 years of experience working with individuals with MS (H.G.).

Measures

Gaze stabilization was determined using vHIT goggles (GN Otometrics) (Figure S2), which have been previously validated in people with aVOR deficits^{11,12} and have been used to demonstrate gaze deficits in persons with MS.⁸ The experimenter administered horizontal (yaw) head impulses to each side to collect at least eight trials suitable for analysis (Appendix S1). The study procedure has been described in detail by Garg et al.⁸ The gaze stabilization variables (Figure 1) were aVOR gain, number of compensatory saccades (CSs) per head rotation, CS latency, and gaze position error. The aVOR gain was determined by dividing the desaccaded eye velocity area under the curve (AUC) by the head velocity AUC, beginning with the onset of the head impulse to the instant when head velocity reverted to zero.⁹ The onset of head movement was preferentially determined by the methods described by MacDougall et al¹³ as the time point 60 milliseconds before maximal yaw head acceleration and confirmed manually by visual inspection. In a few instances in which the MacDougall et al¹³ technique inaccurately identified the onset, the start of head movement was identified as the latest point in time when the head velocity rose above zero and continued to move in the intended direction. Although head rotations to both (left and right) directions were performed, the aVOR gain of the worst-functioning side was used as the dependent variable. The

CSs per head rotation were manually counted for each head rotation and then averaged over the number of rotations. For investigative purposes, a CS was defined as a horizontal eye rotation occurring during the head rotation that assisted a deficient aVOR and occurred in the direction of the vestibular slow component.²⁵ The CS latency was calculated as the time between onset of head acceleration and onset of the first identifiable CS. The gaze position error was measured by subtracting the eye position from the target position when the head velocity returned to zero.

Standing postural sway was assessed using an AMTI OR6-7 series force platform (Advanced Mechanical Technologies Inc, Watertown, MA). The kinetic (COP) data were sampled at 200 Hz. Data were captured using Vicon Nexus (Vicon Motion Systems, Centennial, CO). The following postural sway variables were calculated during a 25-second interval of quiet stance: mediolateral sway amplitude, determined as the maximal excursion of COP in the mediolateral direction; anteroposterior sway amplitude, determined as the maximal excursion of COP in the anteroposterior direction; and total sway path, determined as the cumulative COP excursion during the 25 seconds (Appendix S1). Postural sway has previously been studied in people with MS to detect aberrant sensory contributions using different instrumented techniques; however, the measurement properties of specific variables were not discussed.^{26,27}

Dynamic balance was examined using the FGA. The FGA is a 10-item gait test with established reliability and validity in neurologic populations other than MS that assesses stability during various walking tasks on a marked 6-m (20-ft) length and 12-in-wide walkway.^{28,29}

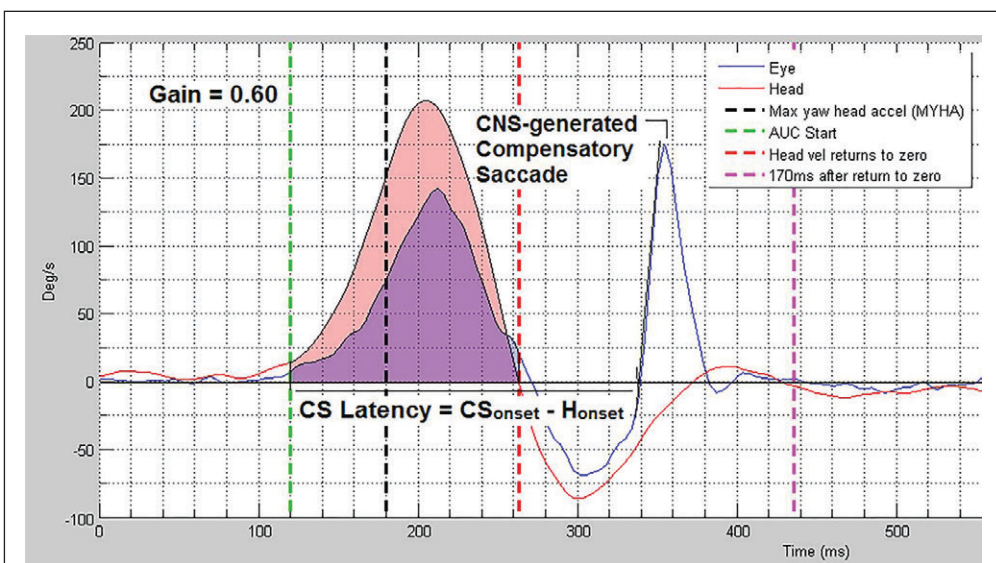


Figure 1. Gaze stabilization measures

Eye velocity has been inverted for ease of comparison. Experimental participant with multiple sclerosis demonstrating decreased angular vestibulo-ocular reflex gain (0.60) and an overt saccade within 170 milliseconds of head velocity crossing zero. Abbreviations: accel, acceleration; AUC, area under the curve; CNS, central nervous system; CS, compensatory saccade; Deg, degree; H_{onset} , onset of head acceleration; Max, maximal.

Data Reduction and Analysis

The collected raw data from the vHIT were exported to custom software written in Matlab (The MathWorks, Natick, MA) for screening and analysis. Standardized screening measures were used to discard trials with blinks and movement artifacts.³⁰ Briefly, trials were screened using the following criteria: visual inspection for appropriateness of eye and head movement; blink identification by detecting either a biphasic deflection of the eye in the lateral plot or an acute deflection in the pitch plot.³⁰ Kinetic data from Vicon Nexus was imported into Visual 3D software (C-Motion Inc, Germantown, MD) for further analysis. The data were filtered using a lowpass, zero-phase shift, Butterworth filter at 20 Hz based on visual inspection of the data and the results of a residual analysis.³¹ IBM SPSS Statistics for Windows, version 23.0 (IBM Corp, Armonk, NY) was used for all analyses.

Data for all dependent variables were examined separately for persons with MS and controls. Test-retest reliability, which reflects the agreement between scores on each testing day, was assessed using the intraclass correlation coefficient (ICC) with a two-way mixed-effects model (ICC[3,1]).³² The ICC point estimators were interpreted using the following criteria: ICC less than 0.5 indicates poor; 0.5 to 0.75, moderate; and greater than 0.75, good reliability.²⁸ Response stability was established by calculations of standard error of measurement (SEM) and minimal detectable difference with a confidence level of 95% (MDD95). The SEM was computed as $SEM = SD \sqrt{1 - \text{estimated reliability coefficient}}$, where SD is the pooled standard deviation of test-retest measures, and the MDD95 (ie, measure of true change) was calculated as $1.96 \times \sqrt{2} \times SEM$.³² The SEM and MDD95 values, expressed in the unit of measurement, describe the limits for change that can be considered above the threshold of measurement error and indicate a true change after treatment. The SEM% and MDD95% were also determined as a percentage of the mean to produce unitless indicators and allow for comparisons. Values for SEM% and MDD95% less than 20% were considered conservative estimates of low measurement error and acceptable response stability.³³

Results

Nineteen persons with MS met the inclusion criteria and participated. The MS group comprised three men

and 16 women with a mean \pm SD age of 53.4 ± 11.7 years, falls per year of 4.2 ± 3.3 , and disease duration (time since diagnosis) of 16.0 ± 11.4 years, and the control group included five men and nine women with a mean \pm SD age of 54.6 ± 11.9 years and falls per year of 0.07 ± 0.27 (Table 1).

The aVOR gain and gaze position error demonstrated moderate reliability in people with MS, and the aVOR gain and CSs per head rotation demonstrated moderate reliability in controls. The CS latency demonstrated poor reliability in both groups (Table 2). The postural sway and dynamic balance measures demonstrated good reliability in people with MS (ICC range, 0.87-0.98) and controls (ICC range, 0.76-0.90) (Table 2).

Irrespective of the group, aVOR gain, CS latency, and all the postural sway and dynamic balance variables exhibited low measurement error (SEM% <20) and, therefore, acceptable response stability. Relative to controls, larger MDD95 estimates for CSs per head rotation and the postural sway measures were seen in people with MS (Table 2). Angular VOR gain and FGA scores demonstrated low (<20%) MDD95% in both groups, suggesting acceptable response stability.

Discussion

This study aimed to examine the psychometric properties of gaze stabilization, postural sway, and dynamic balance measures by assessing the test-retest reliability and response stability between two separate assessments in people with MS and controls. We determined that most gaze stabilization measures demonstrated moderate test-retest reliability and that the postural sway and dynamic balance measures showed good test-retest reliability. The aVOR gain, CS latency, and all the postural sway and dynamic balance variables demonstrated SEM% less than 20, and aVOR gain and FGA scores showed low MDD95%, suggestive of acceptable

Table 1. Descriptive statistics^a

Characteristic	MS group (n = 19)	Control group (n = 14)
Sex, M/F	3/16	5/9
Age, y	53.4 \pm 11.66 (47.80 to 59.04)	54.64 \pm 11.88 (47.78 to 61.50)
EDSS score	4.95 \pm 1.0 [3.5 to 6.5]	NA
Disease duration, y	16 \pm 11.44 (10.49 to 21.51)	NA
Berg Balance Scale score	46.37 \pm 7.10 (42.94 to 49.79)	55.4 \pm 1.26 (54.49 to 56.31)
Falls per year	4.16 \pm 3.35 (2.54 to 5.76)	0.07 \pm 0.27 (-0.08 to 0.23)

Note: Values are given as number, mean \pm SD (95% CI), or mean \pm SD [range].

Abbreviations: EDSS, Expanded Disability Status Scale; MS, multiple sclerosis; NA, not applicable.

^aMost of this table was originally published in Garg H, Dibble LE, Schubert MC, Sibthorp J, Foreman KB, Gappmaier E. Gaze stability, dynamic balance and participation deficits in people with multiple sclerosis at fall-risk. *Anat Rec (Hoboken)*. 2018;301(11):1852-1860.

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Table 2. Reliability (ICC and measurement error) in people with MS and controls

Variable	MS group					Control group								
	Mean day 1	Mean day 2	ICC(3,1) (95% CI)	SEM	SEM%	MDD95	MDD95%	Mean day 1	Mean day 2	ICC(3,1) (95% CI)	SEM	SEM%	MDD95	MDD95%
Gaze stability														
aVOR gain	0.89	0.92	0.72 (0.40 to 0.88)	0.04	4.5	0.11	12.47	0.9	0.91	0.50 (-0.02 to 0.81)	0.04	4.59	0.12	12.72
CSs/HR	0.61	0.49	0.42 (-0.03 to 0.73)	0.27	48.97	0.74	135.73	0.42	0.33	0.75 (0.39 to 0.91)	0.12	31.83	0.33	88.24
CS latency, ms	222.71	248.54	0.01 (-0.51 to 0.52)	48.47	20.57	134.35	57.02	271.45	264.79	0.04 (-0.51 to 0.56)	53.22	19.85	147.53	55.02
GPE, ^o	2.3	2.1	0.71 (0.39 to 0.88)	0.61	27.76	1.69	76.94	2.19	1.95	0.23 (-0.32 to 0.67)	0.69	33.42	1.91	92.63
Postural sway, mm														
ML amplitude	24	22.6	0.92 (0.80 to 0.97)	3.63	15.57	10.06	43.17	9.7	9.5	0.79 (0.39 to 0.94)	1.68	17.54	4.67	48.62
AP amplitude	36.1	34.1	0.87 (0.70 to 0.95)	5.14	14.64	14.24	40.58	20.3	19.6	0.90 (0.68 to 0.97)	2.11	10.57	5.84	29.29
Total sway path	473.2	484.1	0.98 (0.96 to 0.99)	41.94	8.76	116.24	24.29	230.6	242.7	0.76 (0.34 to 0.93)	24.62	10.4	68.25	28.84
Dynamic balance														
FGA score	15	15.47	0.95 (0.88 to 0.98)	1	6.56	2.77	18.19	27.07	27.5	0.82 (0.53 to 0.94)	1.03	3.78	2.86	10.47

Note: Some data in this table were originally presented in Garg et al.⁸

Abbreviations: AP, anteroposterior; aVOR, angular vestibulo-ocular reflex; CI, confidence interval of the difference; CS, compensatory saccade; HR, head rotation; FGA, Functional Gait Assessment; GPE, gaze position error; ICC, intraclass correlation coefficient; ML, mediolateral; MDD95, minimal detectable difference with confidence level of 95%; MS, multiple sclerosis; SEM, standard error of measurement.

response stability. The SEM and MDD values obtained from this study should enhance the interpretation of gaze and postural stability changes seen after treatment in persons with MS and healthy adults during intervention research and during clinical decision making.

Test-Retest Reliability: ICC

The aVOR gain was found to be a moderately reliable measure for persons with MS and controls in this study. Its moderate ICC value is likely due to within-individual variability in aVOR gain. Because hand placement technique³⁴ and head thrust velocities³⁵ have been identified as sources of variability, we used a consistent hand placement technique for all the trials. In addition, the mean \pm SD head velocities administered on the two assessment days were similar ($186.80^\circ \pm 18.21^\circ$ per second on day 1 vs $187.60^\circ \pm 17.65^\circ$ per second on day 2). We also demonstrated moderate reliability for other gaze stabilization measures (CSs per head rotation and gaze position error). To our knowledge, this is the first study to report the test-retest reliability of the horizontal vHIT in persons with MS and controls using the GN Otometrics system. These results concur with those of a previous study of healthy young adults using a different device.³⁶ Future studies should investigate the sources of variability in gaze stabilization assessments and determine ways to minimize it.

Good reliability for postural sway outcomes was found in all the study participants. These findings are consistent with previous work examining test-retest reliability in healthy older adults and individuals with stroke.³⁷⁻³⁹ In addition, the dynamic balance measure exhibited good test-retest reliability in all study participants. Similar results have been demonstrated by previous studies in individuals with stroke²⁹ and Parkinson disease⁴⁰ (ICC > 0.90), emphasizing the usefulness of the FGA in assessing dynamic balance in neurologic populations. Because the FGA includes progressively challenging motor tasks, which addresses the visual, vestibular, and proprioceptive contributions to balance during gait, this test may be better suited for people with MS reporting imbalance and a history of frequent falls. This study demonstrated better test-retest reliability of the FGA in persons with MS (ICC, 0.95) compared with controls (ICC, 0.82). Taken together, these results support the use of postural sway and dynamic balance assessments in clinical practice and as relevant outcome measures in research trials using these populations. However, such

results should be combined with the information on measurement error of these instruments.

Response Stability: SEM, MDD95 and SEM%, MDD95%

In this study, information from response stability metrics allows the clinician or researcher to interpret an observed change in an outcome as a potential product of measurement error or as a meaningful change in vestibular physiology or postural behavior. This study found low measurement error (SEM, SEM%) for aVOR gain, CS latency, and all the postural sway and dynamic balance variables. Low MDD95 and MDD95% values were seen for aVOR gain and FGA scores only.

Regardless of group membership, aVOR gain demonstrated acceptable response stability, suggesting that a relatively small magnitude of change is required to demonstrate a real change in performance as opposed to the other gaze stabilization measures (Table 2). These results support the utility of aVOR gain as a sensitive gaze stability outcome in persons with MS as well as in healthy individuals. The contributors to increased measurement error in other gaze stabilization measures may include the location and severity of demyelination, the stability and degree of vestibular dysfunction in the person being tested, age, the testing instrumentation, and the testing technique. Further research is warranted to characterize common sources of measurement error and recommend steps to minimize this error for diagnostic, prognostic, and rehabilitative purposes.

Low error (SEM% <20%) in the postural sway and dynamic balance measures suggests acceptable response stability for research and clinical practice. Among the COP-based variables, total sway path consistently demonstrated the lowest MDD95 estimates and percentage values, suggesting less measurement error than other outcomes. Previous studies have found similar results in individuals with stroke³⁹ and healthy individuals.³⁷ Because this study demonstrated a range of MDD95% estimates (<50%) for other postural sway variables, further research with larger sample sizes is needed to appropriately define population-specific outcomes of postural sway. This study found better response stability for the FGA in both groups as opposed to previous reports,^{29,40} however, higher estimates of SEM and MDD95 were seen in people with MS compared with healthy older adults. Clinically, this implies that to identify a real performance modification, a greater change is required in people with MS than in neurologically healthy individu-

als. Although there is no consensus on the acceptable amount of measurement error,³³ these findings support the use of some of these postural sway and balance assessments in clinical and research settings for persons with MS as well as healthy adults.

Limitations and Conclusion

Small sample size and heterogeneity may have influenced the results, and, therefore, a larger study that includes homogenous groups of older adults and people with MS is warranted to support the utility of these gaze assessments in clinical practice. In addition, the current reliability data may not be generalized to other populations with neurologic and vestibular conditions. By design, this study chose to assess the test-retest reliability with a single rater and across different days; therefore, these results cannot be applied toward within-day assessments and multiple raters.

In conclusion, the present study found moderate reliability of gaze stabilization measures and good reliability of postural sway and dynamic balance measures in persons with MS as well as age-matched controls. Although the aVOR gain and FGA measures may be stable across repeated testing sessions, a relatively larger change in performance may be needed to detect real change for the remainder of the gaze stabilization and COP-based measures. □

PRACTICE POINTS

- Accurate vestibular sensations allow for stable gaze and postural responses during static and dynamic positions requiring balance, thus highlighting the need for such assessments in persons with MS at fall risk.
- This study addresses the insufficient information on clinimetric properties of gaze and postural assessments in MS, which might have been a hindrance to its application in clinical settings. Acceptable reliability and low values of minimum error and minimal detectable difference for gaze stability (angular vestibulo-ocular reflex gain), postural sway (total sway path), and dynamic balance (Functional Gait Assessment) measures were found.
- Therefore, clinicians can use both instrumented and functional tests to document gaze and postural responses in persons with MS.

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