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Features of gait most responsive to tap test in normal pressure hydrocephalus

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Abstract

Objective: To identify components of gait associated with a positive tap test (TT) in patients with idiopathic normal pressure hydrocephalus (iNPH).

Patients and methods: Thirty-three patients with iNPH underwent clinical evaluation pre- and post-TT and were classified as responders (Rs) or non-responders (NRs). Elements of gait were assessed with a formal standardized Gait Scale and compared between groups.

Results: Analysis of pre/post-TT group differences revealed an interaction for Total Gait Score and Walking Score, with improvements in responders only. Total Gait Scores improved by 29% in the Rs and 4.85% in the NRs. Rs showed significant post-TT improvements on a timed 10 m walk, turning, and balance. Tandem walking, turning, truck balance and start stop hesitation showed trends toward improvement.

Conclusions: The classic features of gait often used in determining *diagnosis* of NPH (wide based stride, reduced foot-floor clearance, and small steps) were not helpful in identifying responders to the TT. Walking speed, steps for turning, and tendency towards falling were most likely to improve post-TT. These straightforward measures can readily be adapted into clinical practice to assist in determination of shunt candidacy.

Keywords: Idiopathic normal pressure hydrocephalus; Gait disorders; Neurologic; Tap test, Candidacy for shunt; Gait assessment

1. Introduction

Idiopathic normal pressure hydrocephalus (iNPH) is a syndrome consisting of a clinical triad of gait disturbance, cognitive dysfunction, and urinary symptoms first described by Hakim and Adams in 1965 [1]. The gait disturbance is typically the most prominent clinical feature of iNPH and is often the first symptom to develop [2,3]. Dramatic gait improvement can be achieved in some patients with the placement of a shunt; [4,5] however, the procedure can be associated with as much as 50% morbidity, including permanent neurological deficits, intracerebral hemorrhage, subdural hemorrhage, meningeal infection, as well as death [6–9]. Given the potential risk associated with this intervention, there is a need for improved patient selection criteria for shunt surgery. The most widely used prognostic test to assess candidacy for shunt placement is the CSF tap test, also called a large volume lumbar puncture. While this test has not undergone rigorous evaluation in carefully controlled prospective evaluations and is not required for diagnosis, the tap test (TT) is commonly used to prognosticate shunt responsiveness. Clinical improvement following TT is one of the few established prognostic indicators of a positive response to shunting in patients with iNPH [10], yet there is wide variability in how response to the TT is determined [11,12].

Standard of care in evaluating TT response typically involves subjective assessment by the clinician of whether an individual's gait has changed post-tap. This can be extremely challenging since the degree of change may be subtle in some cases. Further, the time frame in which improvement may be

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observed is variable across patients; therefore, determination of whether a patient has responded is sometimes partially based on the subjective impression of improvement by the family and caregivers after the patient leaves the clinician's office. A positive TT response has been shown to have good positive predictive value of shunt response [10]. However, failure to respond to TT does not necessarily indicate a negative treatment outcome. The TT has a high false negative rate, likely owing to the subtlety of the determination of post-tap changes [13–15].

The literature examining response to the TT is limited and often based on subjective clinician's ratings as opposed to objective measures of change. To date, few studies have employed quantitative gait assessment to describe the NPH gait disturbance or to examine which aspects of the gait disorder are most responsive to TT. One small study of 10 NPH patients by Stolze et al. found that only stride length improved following the TT [16]. Another study ($n = 10$) of NPH patients found increased speed of movement post-TT [17]. More recently, Bugalho and Guimaraes [18] assessed gait in a small sample of NPH patients and showed that hypokinesia, but not disequilibrium, responded to TT. Further, patients with frontal release signs at baseline were less likely to respond to TT. The studies are generally small and although there is some overlap, specific aspects of gait that are evaluated vary between studies. In a well regarded study, Wikkelso and colleagues defined improved gait as >5% post-tap change on the average of three walking trials which consisted of counting number of steps required to walk 18 m [11,19]. The gait disturbance was characterized by short and variable stride length, freezing, and impaired turning in the majority of patients, but additional information was not provided on how gait was measured or which aspects specifically improved post-tap [11]. Clearly, there is a need for specific quantitative measures of gait improvement to aide in the determination of surgical candidacy and to evaluate improvement following shunt placement.

The Gait Scale, a useful quantitative measure of gait impairment in NPH patients, is a component of a larger measure developed as part of the Dutch normal pressure hydrocephalus study [20]. The Gait Scale evaluates various aspects of gait, including walking speed, stride length, stance, foot-floor clearance, balance, tandem walking ability, turning ability, and start hesitation. Although the utility of this scale to characterize pre/post-TT gait changes has not been well documented, it is an objective measure which captures the unique gait features associated with iNPH.

To aid in clinical decision-making and to avoid putting patients at unnecessary surgical risk, improved confidence in the results of a diagnostic TT is desirable. Given that the determination of TT response typically depends on the clinician's

Table 1
The Gait Scale

	Walking Score (WS)
Able to walk independently	
Tandem walking disturbed	2
Turning disturbed	2
Trunk balance disturbed, sway	2
Wide based stride	2
Small steps	2
Reduced foot-floor clearance	2
Start hesitation	2
Tendency toward falling	2
Total	WS = 0–16
Able to walk with assistance	WS = 18
Not able to walk at all	WS = 20

Number of steps and seconds required for a 10 m walk (average of three attempts) in patients walking independently*

Number of steps	Step Score (SS)	Number of seconds	Time Score (TS)
<13	1	<10	1
13–15	2	10–11	2
16–18	3	12–13	3
19–21	4	14–15	4
22–25	5	16–18	5
26–29	6	19–21	6
30–33	7	22–24	7
34–38	8	25–27	8
39–43	9	28–30	9
>43	10	>30	10

Gait Scale Total Score = WS + SS + TS = (Range = 2–40). Reprinted with permission. Boon AJ, Tans JT, Delwel EJ, et al. (1997). Dutch normal-pressure hydrocephalus study: baseline characteristics with emphasis on clinical findings. European Journal of Neurology, Blackwell Publishing. *Original scale used the average of three trials.

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subjective assessment of change, identification of specific gait features most likely to respond to the TT would be of clinical importance. The purpose of this investigation was to identify the components of gait that respond to diagnostic tap test in patients with suspected iNPH.

2. Methods

2.1. Subjects

Participants included patients identified with probable iNPH according to consensus criteria [21] who were evaluated at the Cornell Memory Disorders Program. Thirty-three patients underwent TT as part of an iNPH evaluation during the study time frame. All patients gave written informed consent to participate in the protocol that was approved by the Weill Medical College of Cornell University Institutional Review Board.

2.2. Tap test evaluation

Each patient underwent a spinal tap procedure whereby 40–50 cc of cerebrospinal fluid was removed by lumbar puncture. Gait was formally assessed pre- and post-tap with the Gait Scale (Table 1) [20], which was originally developed as part of the Dutch normal pressure hydrocephalus study. The Gait Scale assesses gait in iNPH patients, and consists of a Walking Score of 0–20, a Step Score of 1–10, and a Time Score of 1–10; all scores are added to obtain a total score (range = 2 [normal] to 40 [severely impaired]). The Walking Score is a measure of eight qualitative aspects of gait rated dichotomously as either normal (0 points) or disturbed (2 points). The Step Score is based on the number of steps required to walk 10 m. The Time Score is based on the amount of time required to walk 10 m. Cognitive function was also assessed pre- and post-tap with mental status screening (Folstein Mini Mental State Exam [22]) and a comprehensive battery of formal neuropsychological measures to be reported elsewhere (Tsakanikas, D., unpublished doctoral thesis). Self-reported mood was assessed with the Geriatric Depression Scale [23]. Post-tap assessments were conducted within 2–4 h after the TT.

2.3. Classification of responders and non-responders

Standard of care for assessing responsiveness to the tap test typically involves the evaluation of gait by a neurologist as well as consideration of the patient and family members impression of change. While standardized gait Scales are available, they are primarily used for research and not clinical purposes. In this study, each patient was evaluated pre- and post-TT by an experienced neurologist (NRR) and was rated as a TT responder (R) or non-responder (NR). For the purposes of this study, we classified patients in a manner consistent with standard of care, which consisted of a complete neurologic exam including evaluation of gait, bedside cognitive exam, and interview with the subject and a caregiver/collateral source.

2.4. Statistical analysis

The data were analyzed using the SPSS software package. Rs and NRs were compared on demographic and disease variables such as age, years of education, duration of symptoms, overall mental status (Mini-Mental Status Exam; MMSE), and level of depressive symptomatology (Geriatric Depression Scale; GDS) using an independent sample *t*-test. Bonferroni corrections were conducted and the significance level (*p*-value) was adjusted for each group of comparisons. Specific *p*-values are supplied with each group of analyses below. Pearson Chi-squared test was employed to compare groups with respect to gender and handedness. Mean Total Gait Score, Walking Score, Step Score and Time Score (significance set at $p \leq .0125$), as well as mean number of seconds and mean number of steps needed to walk 10 m and mean number of steps needed for an 180° turn were compared using independent sample *t*-tests (significance set at $p \leq .0166$). Group differences for the individual components of the Gait Walking Score were assessed using the Pearson Chi-Square test (significance set at $p \leq .006$).

Repeated measures analysis of variance (ANOVA) was employed to assess pre/post-TT improvements in Total Score, Walking Score, Step Score and Time Score (significance set at $p \leq .0125$). McNemar Chi-Square test as utilized to compare pre and post scores for each of the individual components of the Walking Score within both the R and NR

Table 2
Demographic characteristics of the sample ($n = 33$)

	Responders ($n = 23$)	Non-responders ($n = 10$)	*p*-value
Age, mean (S.D.)	79.5 (4.5)	77.0 (8.15)	NS
Years of education mean (S.D.)	15.4 (4.2)	14.6 (1.9)	NS
Gender (%male)	70%	50%	NS
Handedness (%right handed)	87%	100%	NS
Symptom duration (months)	39.8 (32.7)	30.7 (19.1)	NS
MMSE, mean (S.D.)	22.9 (5.4)	25.0 (5.7)	NS
GDS, mean (S.D.)	8.6 (5.5)	10.9 (9.2)	NS

Key: S.D. = standard deviation; GDS = Geriatric Depression Scale, MMSE = Mini-Mental Status Exam.

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Table 3
Association of baseline gait characteristics with tap test response

	Responders ($n = 23$)	Non-responders ($n = 10$)	p-value
Walking Score, mean (S.D.)	12.2 (4.5)	8.8 (5.5)	0.076
Step Score, mean (S.D.)	1.9 (1.5)	2.1 (2.8)	NS
Time Score, mean (S.D.)	3.5 (3.1)	2.9 (3.0)	NS
Total Gait Score	17.3 (7.7)	13.8 (10.6)	NS
Mean # steps 10 m walk, mean (S.D.)	12.3 (5.9)	9.5 (3.5)	NS
Mean # sec 10 m walk, mean (S.D.)	14.8 (10.0)	10.4 (4.0)	NS
Mean # steps 180° turn, mean (S.D.)	5.6 (2.4)	4.7 (2.0)	NS
Elements of Walking Score			
Tandem Walking, %disturbed	96.0%	90.0%	NS
Turning	91.3%	90.0%	NS
Trunk balance	73.9%	40.0%	0.063
Wide-based stride	69.6%	30.0%	0.035
Small steps	65.2%	40.0%	NS
Foot-floor clearance	69.6%	40.0%	NS
Start hesitation	56.5%	50.0%	NS
Tendency toward falling	73.9%	50.0%	NS

Key: S.D. = standard deviation; NS = not significant.

groups (significance set at $p \leq .006$). Comparisons between pre and post scores for mean number of steps on the 10 m walk, mean time on the 10 m walk, and mean number of steps for the 180° turn were conducted using the paired sample t-tests within both the R and NR groups (significance set at $p \leq .0166$).

3. Results

Demographic characteristics of the sample are provided in Table 2. Rs and NRs were comparable with respect to age, gender, handedness, and years of education. The mean age of Rs and NRs was 79.5 and 77.0 years, respectively. A greater number of participants in the R group were male, but this was not statistically significant. Both groups were fairly highly educated (R mean = 15.4 years; NR mean = 14.6 years), reflecting the patient population seen at the Cornell Memory Disorders Program. Mean duration of symptoms, overall mental status (MMSE) and degree of self-reported depressive symptoms (GDS) were comparable between the two groups. Overall, patients in both groups had been experiencing symptoms of iNPH for an average of 2.5–3.5 years and experienced at least mild mental status decline.

The Rs and NRs were compared on three components of the pre-tap Gait Scale—the Walking Score, Step Score, and Time Score, as well as the Total Gait Score (Table 3). No differences between R and NR were observed in pre-tap Total Gait Scores. Of the three components, the Walking Score showed a trend toward statistical significance, with participants in the R group being more likely to have impaired Walking Scores at pre-tap evaluation (Rs: 12.2; NRs: 8.8). While the scores of the R group were more impaired across all of the Gait subscores, no statistically significant differences were observed between groups in mean number of seconds and steps needed to walk 10 m and mean number of steps needed for an 180° turn. Walking Score is calculated based on eight different criteria (see Table 1). Analyses revealed that the component of the Walking Score that differed most between R and NR was wide based stride, with 69.6% of R showing a disturbance in this gait feature, as compared to 30.0% of NRs ($p = .035$); and this difference represented a trend toward significance. There was also a slight trend toward significance for Trunk balance, with 73.9% of Rs and 40% of NRs showing impairment in this feature of gait. Table 3 shows the percentage of patients in each group with disturbances in each feature of gait.

The main analyses were conducted to determine which specific components of the Gait Scale showed improvements post-TT in Rs and NRs. Repeated measures ANOVA revealed significant main effect of Time (pre vs. post) for both the Walking Score ($p = .002$) and the Total Gait Score ($p = .004$), with improvements seen post-tap. However, there was a significant group (R vs. NR) by time (pre-tap vs. post-tap) interaction for the Walking Score ($p = .004$) and a trend for the Total Gait Score ($p = .008$), with improvements seen following the TT in R group but not in NR group (Tables 4 and 5). Examination of the percent changes in Total Gait Scores (pre-tap to post-tap) revealed that the scores of the Rs improved by a mean of 29% while the scores of the NRs improved by a mean of 4.85% ($p < 0.001$).

Analyses revealed a significant difference for the mean number of steps needed for an 180° turn following tap-test in the R group, but not in the NR group. There was also a trend toward significance for Rs on mean number of seconds needed to walk 10 m. No significant pre-post differences were observed in mean number of steps needed to walk 10 m for either group (Table 6). Changes in the individual components of the Walking Score were examined for both the R and NR groups. Tendency toward falling showed a trend for improvement in the Rs, with scores on this measure changing from disturbed to normal on this gait feature post-tap.

Table 4
Pre- and post-tap Gait Scores for responders and non-responders

	Responders ($n = 23$)	Non-responders ($n = 10$)[a]
Walking Score, mean (S.D.)		
Pre-tap	12.2 (4.5)	8.0 (5.2)
Post-tap	8.7 (5.3)	7.8 (5.0)
Step Score, mean (S.D.)		
Pre-tap	1.9 (1.5)	2.0 (3.0)
Post-tap	1.7 (1.5)	2.0 (3.0)
Time Score, mean (S.D.)		
Pre-tap	3.5 (3.1)	2.5 (3.0)
Post-tap	2.8 (3.3)	2.4 (3.0)
Total Gait Score, mean (S.D.)		
Pre-tap	17.3 (7.7)	12.5 (10.4)
Post-tap	13.1 (9.0)	12.2 (10.3)

Key: S.D. = standard deviation.
[a] Number of subject vary from 8 to 10 due to missing data.

Trends toward improvement were also observed following TT in the R group for several gait features including, tandem walking, turning, trunk balance, and start–stop hesitation. No changes in the individual components of the Walking Score were observed for the NR group.

We conducted supplementary analyses in a small subset of patients ($n = 8$) who underwent shunt placement and were followed for up to a year with systematic gait evaluation. Paired sample *t*-tests revealed a significant improvement in Total Gait Scores ($p = .013$). Overall, patients Total Gait Scores improved 44% from baseline. A trend toward significance was observed for Time Score ($n = 4$; $p = .058$), but no differences were observed for the Walking Score or Step Score.

Table 5
Analysis of variances: group (R vs. NR) by time (pre-tap vs. post-tap)

	d.f.	*F*	*p*-value
Walking Score (WS)			
Main effects: group (R vs. NR)	1	0.88	NS
WS (pre vs. post)	1	11.92	0.002
Interaction: WS X group	1	9.46	0.004
Step Score (SS)			
Main effects: group (R vs. NR)	1	0.27	NS
SS (pre vs. post)	1	0.20	NS
Interaction: SS X group	1	1.47	NS
Time Score (TS)			
Main effects: group (R vs. NR)	1	0.92	NS
TS (pre vs. post)	1	2.44	NS
Interaction: TS X group	1	1.31	NS
Total Gait Score (TB)			
Main effects: group (R vs. NR)	1	0.21	NS
Score (pre vs. post)	1	9.72	0.004
Interaction: Score X group	1	8.02	0.008

Key: d.f. = degrees of freedom; S.D. = standard deviation; NS = not significant.

Given the small sample size individual components of gait were not analyzed.

4. Discussion

The results of this study demonstrate that specific aspects of gait, namely, walking speed, turning, and tendency towards falling, are features most likely to change following TT in those identified as responsive to the test. When examining

Table 6
Improvement following tap test for responders and non-responders groups

Time, step, and turn scores	Responders ($n = 23$) mean (S.D.)	*p*-value	Non-responders ($n = 8$) mean (S.D.)	*p*-value
Mean # steps 10 m walk				
Pre-tap	12.3 (5.9)	NS	8.6 (2.2)	NS
Post-tap	11.2 (5.4)		8.4 (1.9)	
Mean # sec 10 m walk				
Pre-tap	14.8 (10.0)	0.026[±]	9.2 (1.8)	NS
Post-tap	12.7 (8.5)		8.5 (2.3)	
Mean # steps 180° turn				
Pre-tap	5.6 (2.4)	0.010[*]	4.2 (1.3)	NS
Post-tap	4.5 (1.9)		3.3 (0.84)	
Elements of Walking Score	**%Improved**	***p*-value**	**%Improved**	***p*-value**
Tandem	22%	0.063	0%	NS
Turning	22%	0.063	0%	NS
Trunk balance	30%	0.070	0%	NS
Wide-based stride	13%	NS	0%	NS
Small Steps	1%	NS	1%	NS
Foot-floor clearance	22%	NS	0%	NS
Start hesitation	30%	0.070	0%	NS
Tendency towards falling	30%	0.016[**]	0%	NS

Key: S.D. = standard deviation; NS = not significant.
[±] Trend towards significance after Bonferroni correction.
[*] Significance set at $p < 0.016$.
[**] Trend towards significance after Bonferroni correction set at $p < .006$.

pre-tap gait in isolation, wide based stride was more often impaired in those who were subsequently classified as TT responders. Trunk balance was another feature that appeared to differ between the groups at the pre-tap assessment, but this difference did not reach statistical significance. Of note, the features of gait often used in determining *diagnosis* of NPH were not particularly helpful in identifying individuals who responded to the tap procedure. In their small study of tap test responsiveness, Bugalho and Guimarães [18] also found that at least one principal feature of the NPH gait (i.e., disequilibrim) was not associated with tap test responsiveness.

This study contributes to the literature on iNPH in that the features of iNPH gait were quantified with a clinical rating scale. Scores on an objective clinical rating instrument, the Gait Scale [20], showed statistically significant differences in the Walking subscore as well as the Total Gait Score in responders as compared to non-responders. Those judged as responsive to the TT improved on the Total Gait Score (pre-tap to post-tap) on average 29%, as compared to a mean of 4.85% in the non-responders, and this difference was clinically as well as statistically significant. Although the Gait Scale used in this investigation has not been widely studied, it is among only a few measures that have been developed to quantify gait impairment in NPH [16,18]. Other measures are available, however, each scale has limitations and none have undergone rigorous validation as an outcome measure in iNPH. The greatest limitation of the Gait Scale is that it employs only dichotomous ratings, with features of gait classified as either as 'normal' or 'disturbed.' As a result, patients who improve post-tap, but whose performance in that feature remains compromised would continue to receive a rating of disturbed. The Gait Score would not reflect change, although improvement exists. Despite the limitations of this instrument, it is an improvement over current methods. A neurologist's clinical judgment, although subjective, is standard of care for assessing response to tap test.

It is important to point out that although gait testing is perhaps the most important component of TT response, it should not be used in isolation in the determination of shunt candidacy. Cognitive test results, CSF opening pressure, as well as the subjective impression of both the examiner and family members are all important aspects of the presentation that should be considered in the determination. Further, shunt responsiveness is influenced by several factors that are not assessed by TT (e.g., age, duration of symptoms, medical comorbidities, shunt type and setting, etc.). TT responsiveness in this study was judged by an expert's opinion, which by definition, is a subjective measure. Although global clinical impression is considered here as the gold standard, the subjective nature of this determination can be considered a limitation.

The present study was based on a clinical sample of patients with suspected iNPH presenting for TT evaluation, and as a result, comorbities were not excluded. The population consists of older adults that may have peripheral neurologic involvement or other factors such as arthritis that may affect their mobility. However, this is a representative sample of the types of patients likely to undergo TT for iNPH. Not unlike other studies in this population, the sample size is relatively small, which may explain why apparent trends did not reach statistical significance. Nevertheless, close examination of the data suggests that some findings may be of clinical, if not statistical, significance. It is also worth noting that the Rs had poorer scores than the NRs on objective motor testing. There were no significant differences on any of the other clinical variables (symptom duration, cognitive compromise, depression) that would suggest more advanced disease. It is possible that as a result of their being more impaired motorically, there was more room for improvement on post-tap motor measures (i.e., regression to the mean).

Surprisingly, the "classic" features of the NPH gait—wide based stride, reduced foot-floor clearance, and small steps, did not differentiate responsiveness to the TT. This may potentially be explained by the scoring method used (dichotomous rating of 'disturbed" vs. 'normal'), where an individual may improve in an aspect of gait but still be compromised and receive a rating of 'disturbed.' Since participants underwent post-TT gait assessment 2–4 h following removal of CSF, it is possible that some aspects of gait that were unchanged at post-TT assessment may have improved in subsequent hours. There are no systematic studies investigating timing of response to TT, but clinician's assessment following a 2–4 h window is consistent with standard of care [24]. In clinical settings, physicians may consult with family members regarding apparent changes in the patient's gait within 24 h of the TT. While the current findings should be considered in the context of these methodological issues, the result of this study suggest that the classic gait features that are important in the diagnosis of an iNPH may not be the same aspects of gait that respond immediately to CSF removal via TT. Further studies should seek to determine whether the aspects of gait that improve following TT are correlated with post shunt gait improvements.

The findings from this study are directly applicable to clinical care in the determination of shunt candidacy by helping to identify the particular features of gait that should be the focus of clinical attention following the tap test. These relatively straightforward measures (time to walk 10 m, number of steps to turn, and tendency towards falling) can be implemented quickly and easily into clinical practice and improve the clinician's confidence in the diagnostic accuracy of the TT. Future studies should focus on improving quantitative measures of gait that allow for assessment of more subtle changes in gait features as well as prognostic values for shunt responsiveness in the treatment of iNPH.

Competing interests

One author (NRR) has received grant support and serves as a consultant to Codman. The other authors do not have any competing financial interests to disclose.

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