Quantitative and Clinical Measures of Static Standing Balance in Hemiparetic and Normal Subjects

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Static standing balance was compared in 10 subjects with hemiparesis resulting from a cerebrovascular accident (33–71 years of age), 10 young normal subjects (22–40 years of age), and 10 older normal subjects (48–78 years of age) using a quantitative maximal load test and a clinical evaluation. The maximal load test required subjects to maintain a standing position against static loads applied at the waist (sagittal and frontal planes). Maximal loads were recorded as a percentage of body weight at the point when subjects could no longer hold the initial standing position. Effects of mechanical and cognitive factors were minimized in the maximal load test. Hemiparetic subjects had significantly lower maximal loads and clinical balance scores than both normal subject groups. Maximal loads of the young and older normal subjects were comparable, but the older subjects had lower clinical scores than the young subjects. Low correlations between subjects’ scores on the two tests imply that each test yielded different information about static balance. Implications of the study results for the evaluation and treatment of balance deficits in hemiparetic persons are discussed.

Key Words: Aging/postural control; Hemiplegia, evaluation; Human postural control; Postural disorders.

Clinical assessments of standing balance for hemiparetic patients tend to be gross, qualitative evaluations of patient’s ability to maintain postures or withstand self-generated or external forces while standing. Such clinical tests are useful descriptive tools for documenting balance deficits, and the results of these tests are correlated with independence in ambulation. Clinical balance tests, however, have limited value in delineating the problems that underlie the observed deficits. Consequently, subjective impressions rather than objective data typically provide the basis for physical therapists’ assumptions about the causes of balance dysfunction in patients with hemiparesis and hence for treatment plans aimed at improving patients’ balance function.

One practical difficulty in determining the specific causes of balance disorders in patients with hemiparesis or other populations is that standing balance can be influenced by various mechanical, cognitive, physiological, and sensorimotor factors. A valid conclusion about the importance of a particular factor to a patient’s balance problem, therefore, requires physical therapists to evaluate balance while temporarily minimizing the effects of other potentially important factors. This principle is recognized, for example, in the classic Romberg test, which patients perform both with eyes open and eyes closed, and in more recent tests that evaluate contributions of vestibular, visual, and somatosensory systems to balance dysfunction. Less attention has been paid to how mechanical and cognitive factors contribute to balance dysfunction in hemiparetic persons.

The primary purpose of this study was to determine the maximal static (constant over time) loads that hemiparetic persons can hold and still maintain a controlled standing posture compared with healthy individuals of similar ages. The maximal static load that an individual can hold while standing in a particular posture is a mechanical limitation on how well an individual can withstand external or self-imposed disturbances to balance, whether those disturbances are static or dynamic (changing over time). The inability of hemiparetic persons to voluntarily exert normal static torques while standing might account partly for reported differences between hemiparetic and healthy persons’ quiet standing patterns and their responses to rapid external or self-generated disturbances. A limited ability to generate torque against loads, rather than or in addition to other sensorimotor deficits, could account for balance dysfunction in some persons with hemiparesis.

Several recent studies have shown correlations between hemiparetic persons’ muscular strength (estimated by manual muscle tests or maximal voluntary forces or torques exerted during dynamometry) and their performance on gait or balance tasks. It is not known, however, whether persons
with hemiparesis can remain standing when loads are applied to the body that a neurologically unimpaired person could withstand. Indeed, few data have been published on the magnitude of loads that can be held in both the sagittal and frontal planes during standing by persons of various ages with normal balance function. Comparisons of maximal loads that can be held by different populations require that the potential effects of other factors are minimized. For example, foot placement, weight-bearing, and postural sway influence the initial mechanical state of the body and, therefore, its mechanical response to a load. Also, if loads are applied rapidly or if load direction or amplitude is unpredictable, then individual differences in maximal loads might reflect differences in the time required to generate active restoring torque, not in the magnitude of the torque. The relevance of these particular factors is supported by reports that hemiparetic and elderly individuals often have abnormal weight-bearing and foot-placement patterns, greater sway trajectories and velocities during quiet standing, and longer response times compared with young neurologically unimpaired individuals. An adequate description of the ability of hemiparetic and normal groups to hold static loads while standing requires that the effects of extraneous factors be minimized. Because changes in extraneous factors occur with age, comparisons of hemiparetic and normal maximal loads should be made between groups of similar ages.

This study compares the maximal static loads that hemiparetic young and older normal subjects could hold while maintaining a constant standing position when the effects of foot placement, weight-bearing, speed of load application, and predictability of the load were minimized (maximal load test). Maximal loads were assessed in both the frontal (right, left) and sagittal (forward, backward) planes. We hypothesized that even under these relatively controlled conditions, the young normal subjects would hold higher loads than the older normal subjects, who in turn would hold higher loads than the hemiparetic subjects. We also hypothesized that hemiparetic subjects would hold lower loads applied on their paretic side than on their unimpaired side. Finally, a clinical evaluation of each subject's balance function was obtained. The clinical evaluation had fewer constraints on factors that were minimized in the maximal load test. Results of the maximal load and clinical balance tests were correlated to determine whether the two tests provided similar information about standing balance.

METHOD

Subjects

A total of 30 subjects (10 young normal subjects, 10 older normal subjects, 10 subjects with hemiparesis secondary to a unilateral cerebrovascular accident [CVA]) were tested. The young normal group consisted of 7 women and 3 men aged 20 to 40 years ($\bar{X} = 30.5, s = 5.5$). Six women and 4 men aged 48 to 78 years ($\bar{X} = 64.8, s = 10.9$) comprised the older normal group. The normal subjects were selected from the staff and volunteers of the Rehabilitation Institute of Chicago (RIC) by a sample of convenience. Ten hemiparetic subjects were selected from the outpatient population of the RIC by a sample of convenience. The 3 female and 7 male hemiparetic subjects ranged in age from 33 to 71 years ($\bar{X} = 52.7, s = 12.8$). Five subjects had right cerebral lesions, and 5 subjects had left cerebral lesions. Time since the onset of hemiparesis ranged from 6 to 235 months ($\bar{X} = 73.1, s = 81.4$). Hemiparetic subjects were required to stand independently and could ambulate independently (3 subjects used ankle-foot orthoses, and 7 subjects used straight canes). Informed consent was obtained from all subjects.

Instrumentation

External static loads consisted of free weights attached to each subject with a nonelastic cord tied to a belt around the subject's waist. The cord went over a pulley fixed to a sturdy metal post at waist height so that the line of pull was perpendicular to the body in either the sagittal or frontal plane (Fig. 1). The weights were applied manually.

Positions of the subject's trunk and hips in the plane of the load were measured (1 mm accuracy) by a battery-powered potentiometer-pulley system attached to the subject with lightweight cords with snaps. The snaps were taped over the subject's greater trochanters and the C7 spinous process for sagittal trials and unilaterally over the acromion process and the greater trochanter for frontal plane trials. The potentiometers were attached to the metal post located behind or lateral to the subject. Signals from the potentiometers were sampled digitally at 200 Hz by a PDP 11/23 computer* that also controlled the visual displays for the targets and provided the subject with on-line feedback about hip and trunk positions during load application. A digital monitor located at the subject's eye level displayed separate targets for trunk and hip

* Newman Computer, PO Box 8610, Ann Arbor, MI 48107.
positions. The targets were two squares of 6-mm width, which was equivalent to 12 mm of movement. Actual movements of the trunk and hips were displayed on the monitor as dots that moved right and left, representing anterior and posterior motion for tests of stability in the sagittal plane and right and left body movements for tests of stability in the frontal plane. The subject had to keep both the trunk and hip positions within the targets so that accuracy in positioning was 12 mm.

**Procedure**

The subject stood wearing flat shoes and orthosis or was barefoot. Some variability in footwear was necessary to accommodate individual needs for comfort or safety while standing for the moderately long (5–10 minutes) intervals required to determine the maximal load in each direction. The subject crossed her or his arms at chest level. The subject’s feet were parallel with the distance between the midpoints of the heels equal to the length of the feet, which standardized the length and width of the support base to each subject’s foot length. We attempted to minimize gross asymmetries in weight-bearing by asking the subject to distribute her or his weight equally in the frontal and sagittal planes by using internal feedback of the pressure on the feet and verbal cues given by the two experimenters (W.A.L. and L.D.). (More precise control of weight-bearing would require additional instrumentation.) As the subject stood quietly in the initial position, five values for trunk and hip positions were recorded by the computer. The means of these values were used to set the initial target positions. The subject practiced assuming the initial position for a few minutes after self-initiated movement away from the target position and manual displacement by an experimenter.

Visual feedback about target and actual positions of the trunk and hips allowed each subject to start every trial in the standard initial posture. Visual feedback was given throughout the experiment. The subject was required to maintain the initial posture during application of each weight. When the weight was applied, the subject held the target position for one to two seconds, after which the weight was removed gradually. Each weight was applied and removed at a slow, constant speed by one experimenter. Verbal cues about the magnitude and timing of the load were given before and during the application of each weight. The first weight applied was 1 lb.† Subsequent loads were increased by 1% (to the nearest 0.5 lb) of body weight. Weights were added until the subject started to lose his or her balance or could not hold the initial position within the 6 mm targets. Loss of balance was considered to occur if 1) the subject had to use her or his hands to remain standing, 2) the subject had to be assisted to prevent a fall, or 3) the subject’s feet began to come up off the floor. The maximal load against which the subject could maintain the initial position was recorded as a percentage of body weight.

The same procedure was performed while weights were applied in the anterior, posterior, left, and right directions. Five-minute seated rest periods were provided between each set of directional trials or upon the subject’s request. One experimenter stood behind and slightly to the side of hemiparetic subjects and older healthy subjects to guard them from falling. To further ensure safety, a chair was placed behind all subjects, and a support was placed at the uninvolved side of hemiparetic subjects.

**Clinical Evaluation**

All 30 subjects received a clinical balance evaluation performed by an experienced physical therapist (L.D.). The balance tests included timed tests of standing balance in regular, tandem, and single-limb stance and a qualitative assessment of tilting reactions (Appendix). These tests were derived from the balance assessment developed by Fugl-Meyer et al29 and standard neurological tests of balance.30 Each item in the balance test was scored on a three-point ordinal scale. The sum of all test item scores was used to describe the subject’s balance function (maximal score = 20). Subjects were also given a short neurological evaluation of sensorimotor function by a neurologist (V.S.).

**Experimental Design and Data Analysis**

A descriptive comparative design was used with the three independent groups (hemiparetic, young, and older subjects). All subjects in each group were tested on the maximal load test in each of the four directions and on the clinical balance test. The maximal load test had one independent factor (group status) and one repeated factor (direction), with maximal load as the dependent measure. Group means, standard deviations, and 95% confidence intervals were used to describe each group’s maximal loads. A mixed factorial analysis of variance was used to evaluate differences in maximal loads associated with group status and load directions. The between-group factor, status, had three levels (hemiparetic, young normal, older normal), and the within-group factor, load direction, had four levels (forward, backward, right, left). A priori hypotheses were tested with planned contrasts, and orthogonal contrasts were used for *post-hoc* comparisons.21 Frequency distributions, medians, and ranges were used to describe the results from the clinical balance tests. A medians test was used to evaluate the significance of differences among the three groups’ clinical balance scores.22 A Spearman rank order correlation coefficient was used to assess the relationship between maximal static loads and clinical balance scores. An alpha level of .05 was adopted for all tests.

**RESULTS**

**Maximal Loads**

Both the young and older normal subjects held higher maximal loads than did the hemiparetic subjects (Fig. 2, Table) as demonstrated by a significant main effect for groups ($F = 10.4; df = 2.27; p < .05$) and a significant planned orthogonal contrast between the maximal loads of the two normal groups and those of the hemiparetic subject group ($F = 5.12; df = 1.27; p < .05$). No significant difference was found between the mean maximal loads held by the young and older normal subjects (planned contrast: $F = 0.02; df = 1.27; p > .05$). A significant main effect for load direction was found ($F = 68.16; df = 3.81; p < .05$). This effect was due to significantly lower (almost 50%) loads in the posterior direction (*post-hoc* orthogonal contrast of the forward, right, and left loads with the backward loads: $F = 34.78; df = 1.81; p < .05$). The interaction of load direction and group status was not statistically significant, showing that the pattern with lower posterior loads was comparable for the three groups.
The maximal loads for hemiparetic subjects held toward and away from the paretic side did not differ significantly (planned comparison using a paired t test: \( t = 0.59, \ df = 8 \)). Figure 2b shows a breakdown of maximal loads for the five subjects with left hemiparesis and five subjects with right hemiparesis.

**Clinical Balance Evaluation**

The frequency distribution of the clinical balance test scores showed that most young normal subjects had perfect scores (Fig. 3a). Eight young normal subjects scored the maximum value of 20 points, and two subjects scored 19 points (median = 20). The older normal subjects' scores were much more variable and often lower than those of the young normal subjects, ranging from 11 to 20 points with a median score of 16.5 points (Fig. 3b). Four older normal subjects had scores as high as those of the young normal subjects. The clinical balance scores of the hemiparetic subjects ranged from 11 to 16 points (median = 13.5) and were lower than those of the young normal subjects (Fig. 3c). The median clinical balance scores differed significantly among the three groups and between the older normal and hemiparetic groups (medians tests: \( \chi^2 = 44.3, \ df = 2; \chi^2 = 22.2, \ df = 1 \)). The scores of nine hemiparetic subjects, however, overlapped with the lower half of the older normal subjects' scores.

**Correlations of Maximal Loads and Clinical Balance Test Scores**

Hemiparetic subjects had significant positive correlations between their clinical balance scores and the maximal loads held in the anterior (rho = .66, \( \df = 8, p < .05 \)) and posterior (rho = .68, \( \df = 8 \)) directions (Fig. 4). Maximal loads held toward the paretic and contralateral sides were not significantly correlated with the clinical balance scores. For the older healthy subjects, the clinical balance scores were significantly correlated with maximal loads only in the forward direction (rho = .53, \( \df = 8 \)). The restricted range of variability of young normal subjects' clinical balance scores made the correlation analysis inappropriate.

**DISCUSSION**

The results of the maximal load and clinical balance tests showed that the hemiparetic subjects had significant deficits in standing balance control compared with young and older normal subjects. This finding is consistent with previous observations of functional balance deficits in persons with hemiparesis.\(^1,2,19\) Although all hemiparetic subjects in this study could stand and ambulate independently and demonstrated a rather high functional level, they still had significantly diminished balance function. Hemiparetic individuals with less functional mobility than the subjects in this study might show even more severe deficits in standing balance control.

**TABLE**

<table>
<thead>
<tr>
<th>Ninety-five Percent Confidence Intervals for Normalized Maximal Loads* for Hemiparetic and Young and Older Healthy Subjects (N = 30)</th>
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* Loads are a percentage of body weight.

\(^b\) CI = confidence interval.
Two lines of evidence suggest that the deficits observed in the maximal load test in the hemiparetic subjects were not due solely to age. First, the older normal subjects' clinical balance scores were significantly higher than those of the hemiparetic subjects, although considerable overlap existed in the frequency distributions for the two groups. Second, hemiparetic subjects but not the older normal subjects held lower maximal loads than the young normal subjects. Thus, the maximal load test was sensitive to balance deficits associated with the neurological disorder but not with age. The finding of similar maximal loads for the young and older normal groups does not imply that all older subjects had normal balance function. The lower clinical balance test scores for most of the older normal subjects compared with those of the young normal subjects indicate some diminution of balance function. The age-related deficits revealed by the clinical balance test are consistent with other studies with relatively few controls on mechanical or cognitive conditions.

The observation that hemiparetic subjects had essentially the same directional pattern of maximal loads as the normal subjects suggests that persons with hemiparesis may be at risk for falls in all directions, at least when they stand in a symmetrical weight-bearing position. The deficits observed in the sagittal and frontal planes may partly explain the typical asymmetrical stance pattern of individuals with hemiparesis in which the support base is effectively lengthened and widened. The diagonal stance may help hemiparetic individuals compensate for some static balance deficits. The idea that the diagonal stance may be advantageous for some patients with hemiparesis contrasts with clinical expectations that stress the need for patients to assume a more symmetrical stance, especially in preparation for walking. The relative benefits of symmetrical and asymmetrical stances could be tested by measuring the maximal loads that hemiparetic subjects can hold in each stance.

The fact that the hemiparetic subjects in this study could hold equally large loads toward and away from their involved side suggests that they were not necessarily more at risk for falls toward the involved side. This inference, however, may have only limited generalizability. Differences in balance control toward and away from the paretic side may be more pronounced when the level of involvement is more severe, the more typical asymmetrical stance is adopted, loads are unpredictable or dynamic, or loads must be held for longer durations.

One noteworthy aspect of the general pattern of maximal loads observed in all subject groups was that the maximal loads that could be held in the posterior direction were only half those held in the other directions. This asymmetry is important because it implies that a given load is about twice as destabilizing in the posterior direction compared with the anterior or frontal directions. Consequently, stability tests in the sagittal plane that use the same magnitude of perturbation in the forward and backward directions may not threaten the general findings of this study.

Fig. 3. Frequency histograms illustrating range of clinical balance scores for (a) young normal subjects, (b) older normal subjects, and (c) hemiparetic subjects.

Fig. 4. Scatterplots showing relationship (best-fit linear regression) between clinical balance and maximal load test scores of hemiparetic subjects for posterior (open square) and anterior (closed square) directions of load.
balance equally in the two directions. To obtain roughly equivalent disturbances, load or positional perturbations probably should be twice as large in the forward direction.

The relationship between the results of the maximal load and clinical balance tests remains to be discussed. Both tests focused primarily on static aspects of standing balance. Static standing balance is clinically tested by asking the individual to assume and maintain different standing positions and is graded according to the length of time the individual can hold the position, the degree of steadiness, and how much manual resistance can be withstood without losing the position. Despite the similar focus of the two tests in this study, however, only minimal correlations were found between scores on the maximal load and clinical balance tests, and then only for hemiparetic subjects in the sagittal plane. The low correlations persisted even when the two items related to tilting reactions were removed from the clinical balance test scores. The most dramatic difference between results of the two tests was obtained with the older normal subjects, whose maximal loads did not differ significantly from those of young normal subjects, despite substantially lower clinical balance scores for the older subject group. The minimal relationship between the two test results indicates that the tests provide different information about balance. The clinical balance test identified the presence of balance deficits but did not distinguish clearly between balance problems associated with aging and those caused by neurological deficits. The maximal load test, in contrast, distinguished between the neurologic and age-related balance deficits but failed to identify balance deficits of the older normal subjects.

We propose that some of the differences in the results of the two tests reflect differences in how the two tests were conducted. In the maximal load test, but not in the clinical evaluation of balance, we attempted to minimize the effects of selected mechanical and cognitive factors (eg, weight-bearing, foot placement, and magnitude and predictability of loads) that might have influenced subjects' scores. The finding that young and older normal subjects could hold similar maximal loads (where the effects of such factors were minimized) but that the older normal subjects had lower clinical balance scores (where those factors were not controlled in any way) is consistent with our supposition that mechanical and cognitive factors can influence balance scores, at least for older normal subjects. Physical therapists, therefore, should recognize the importance of mechanical and cognitive as well as sensorimotor factors when they evaluate balance function in patients.

The reasons why the hemiparetic subjects held lower than normal maximal loads are open to some speculation. We had expected the hemiparetic subjects to hold lower maximal loads than the normal subjects, partly because persons with hemiparesis typically cannot exert normal levels of voluntary torque or force. The observation that the hemiparetic subjects held lower than normal maximal loads in all directions under the controlled conditions of the test is consistent with that line of reasoning. Other studies have reported positive correlations between the maximal forces or torques that subjects can generate and various aspects of standing balance or independent ambulation. However, factors besides the ability to generate torque in lower extremity muscle groups also probably contributed to the lower maximal loads observed in the hemiparetic subjects. Peripheral or central sensory deficits, abnormal reflexes, or disorders in the neural mechanisms of motor coordination or sensorimotor integration could have reduced the maximal loads that the hemiparetic subjects could hold. These factors, as well as the effects of cognitive and mechanical factors that we tried to minimize in the maximal load test, should be even more important in less-controlled situations encountered in the clinic or in daily life. Finally, the total number of disordered systems and interactions among these systems may be more crucial to the integrity of balance control than any one factor.

The reliability of the maximal load test should be determined before its use in further studies. Although the objective nature of the maximal load test and the fairly small 95% confidence intervals found for the maximal loads of each group suggest that the test may be reasonably reliable, more formal evaluation of the test's reliability is needed. Two procedural modifications of the test should also increase its inherent reliability. First, a force platform could provide precise feedback to subjects about the center of pressure. Under the quasi-static conditions of the maximal load test, the location of the center of pressure provides valid information about weight-bearing. Second, a mechanical rather than manual system of applying loads would ensure consistency in the speed of load application.

Clinical Implications

Our results have several implications for the evaluation, treatment, and study of balance control in hemiparetic individuals. First, the maximal load that an individual can remain standing while holding provides an example of a quantitative measure of balance function that could be adopted for use in the clinic. Second, physical therapists who need to distinguish between balance deficits caused by neurological disorders and those caused by age may be able to improve clinical evaluations of balance by standardizing the testing conditions as much as possible (eg, initial weight-bearing and foot placement; size, rate, direction, and predictability of disturbances). Third, recognition that these factors may influence performance on balance tasks could help physical therapists in planning treatment. For example, some hemiparetic patients with balance disorders might benefit from strength training of the lower extremity or trunk musculature. It is also possible the asymmetrical stance of persons with hemiparesis may be compensatory, providing improved balance control over the more "normal" symmetrical stance pattern that often is reinforced in treatment. Such ideas as these clearly warrant clinical investigation. Finally, the effects of mechanical and cognitive factors on standing balance control should be studied in more dynamic conditions, including during disturbances generated by the patient (eg, arm movements) or by external sources (eg, the therapist's manual contact).

CONCLUSIONS

The static balance function of hemiparetic subjects and young and older normal subjects were assessed by two tests. The maximal load test measured static standing balance under well-controlled conditions. The second test was based on standard clinical assessment methods. The results of both tests revealed significant balance deficits in the hemiparetic subjects that were not due solely to age. Differences in the results of the two tests were found, especially for older normal subjects whose scores were similar to young normal subjects.
for the maximal load test but lower for the clinical test. The minimal correlations between the results of the two tests support the conclusion that these two tests provide different information about static balance function. The mechanical and cognitive factors that were controlled in the maximal load test but not the clinical balance test may account for some differences in the results from the two tests.

Acknowledgments. We thank M. J. Blaschak, M. Rogers, D. Shefrin, and S. VandenNoven for their helpful comments on earlier drafts of the manuscript; W. E. Lee for construction of mechanical devices; and Y. Karle for computer programming.

APPENDIX

Clinical Balance Assessment

Criteria for scoring balance test:
1. Number of falls in the past two weeks
   0—more than two
   1—one to two
   2—none
2. Stance test: standard, eyes open and closed; tandem, eyes open and closed
   0—unable to maintain for five seconds
   1—presence of unsteadiness, swaying, or deviation even if the position is maintained for five seconds or more
   2—maintains steady position for more than five seconds
3. Fugl-Meyer et al\(^{19}\): standing without support
   0—cannot stand without support
   1—can stand erect for less than one minute or can stand for a longer time, but sways somewhat
   2—good standing balance, can maintain the balance for more than one minute without insecurity
4. Fugl-Meyer et al\(^{19}\): standing on one lower extremity
   0—the position cannot be maintained for more than a few highly unstable seconds
   1—can stand in a balanced position between four to nine seconds
   2—can maintain a balanced position for more than 10 seconds
5. Tilting reactions in standing, where tilting reactions are defined as lateral flexion of trunk and neck toward side being pushed, rotation of trunk and neck toward side being pushed, or abduction of arm and leg on side being pushed
   0—no reaction observed
   1—delayed or incomplete reactions
   2—normal reactions

<table>
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<td>Frequency of falls</td>
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<tr>
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<td>0 1 2</td>
</tr>
<tr>
<td>Standard stance, eyes closed</td>
<td>0 1 2</td>
</tr>
<tr>
<td>Tandem stance, eyes open</td>
<td>0 1 2</td>
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<tr>
<td>Tandem stance, eyes closed</td>
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REFERENCES