The Effect of Environmental Regulations on Postural Control After Stroke

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Key Words: forecasting • motor control • reaching

Objectives. *The primary objective of this study was to examine the effect of environmental predictability on postural control after stroke. A reaching task for seated subjects was used as the postural perturbation. Trajectory stability (the pathway followed by the subject's body center of pressure with respect to time during the reaching task) was used as the index of postural control. It was hypothesized that trajectory stability would be greater under predictable conditions.*

Method. *A specially designed electromechanical system was used to measure the trajectory stability ratios for 100 subjects, 50 with poststroke hemiplegia and 50 who had not had stroke. All subjects completed a task that required reaching to the left versus reaching to the right, under predictable versus unpredictable conditions. Postural control was measured via a trajectory instability ratio in both the anterior-posterior and medial-lateral planes.*

Results. *Although the effect of predictability on postural control was significant, it was not as hypothesized for both groups. There was greater trajectory stability under unpredictable conditions when reaching to the right as measured in both the anterior-posterior and medial-lateral planes and when reaching to the left as measured in the medial-lateral plane.*

Conclusion. *These findings refute the assumption of the hierarchical, predictable-to-unpredictable-environment model for postural control evaluation and treatment. The relationship between information processing demands and postural skill is probably more complex than the simple linear association implied. Perhaps the two conditions, predictable and unpredictable, should be worked on concurrently, not sequentially.*

Occupational therapists use a variety of therapeutic tasks and activities that require reaching in the assessment and treatment of cognitive-perceptual and postural control dysfunction (Abreu, 1994; Abreu & Hinojosa, 1992). Examples of such tasks are reaching for a cup in the kitchen or touching a target. Performance of therapeutic tasks and activities is influenced by myriad relevant environmental regulators. *Relevant environmental regulators* are all the pertinent parameters derived from people, objects, and conditions that surround the person (Gentile, 1987). The purpose of this study was to examine the effects of task predictability, an environmental regulator, on postural control during reaching while seated for persons after stroke as compared with persons who have not had stroke.

Relevant environmental regulators have a significant and demonstrable effect on reaching tasks and the postural perturbations that they cause. Some regulators that affect reaching tasks are the location and size of the object (e.g., a cup) and whether it is fixed or moving. To accom-

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This article was accepted for publication January 6, 1995.

plish a reaching task, the person must integrate cognitive-perceptual responses with postural control systems while adjusting to environmental perturbations by generating movement strategies (Nashner & Peters, 1990). This integration is accomplished through a complex, multilevel coordination of central and peripheral nervous system responses that are used to regain and maintain balance (Nashner, 1976, 1985). The movement strategies are triggered by proprioceptive, vestibular, and visual cues about body imbalance, and are stored in memory as schema or as an abstract representation of general patterns. Recognition and recall schema are rules or relationships based on previous experiences that allow the person to generate movement or postures that appropriately match the environment (Schmidt, 1975, 1988). According to Schmidt (1975, 1988), the strength of the schema is directly related to the variability of the task or activity. For example, in learning to reach and pick up a cup, it is better to use cups of different sizes, shapes, and weights, and to place them in different locations, than to use the same cup placed in the same place.

Two environmental regulators are the spatial and temporal parameters of the task or activity being performed (Gentile, 1987). These parameters determine, in part, the motor characteristics and behavior of the person while he or she is accomplishing different tasks within a given environment. Spatial parameters include the position and direction of a task; temporal parameters include the time, sequencing, and chronology of the action. The variability of these parameters determines the degree of predictability of the environmental regulator.

Reaching is a postural perturbation that can be performed under a variety of environmental conditions. Each reaching task requires the person to generate a movement strategy that is dependent, in part, on the spatial and temporal parameters of the environment. A *predictable reaching task* is one with fixed spatial and temporal parameters that is attempted under conditions that offer a low degree of perceptual interference or distraction and allow for a slow, self-paced response. An *unpredictable reaching task* has variable spatial and temporal parameters that create a high degree of perceptual interference or distraction and require an anticipatory reaction time for response. Motor responses and movement strategies initiated in response to the postural perturbation caused by the reaching task are based on movement goals and the critical characteristics of the performing environment, including the degree of predictability (Gentile, 1972, 1987; Reed, 1982).

Certain motor learning and action systems theorists have stated that using variability in practice improves retention and transfer of motor skills (Reed, 1982; Schmidt, 1988). Gentile (1972, 1987) stated that closed tasks are more easily acquired in predictable environments and open tasks are more easily acquired in unpredictable environments. *Closed tasks* are those in which the spatial and temporal factors are fixed. Reaching to pick up a cup is an example of a closed task. *Open tasks* have variable spatial and temporal characteristics from trial to trial (Gentile, 1972, 1987; Jarus, 1994). Reaching to pick up a cup from a moving conveyor belt is an example of an open task. Schmidt (1975, 1988), on the other hand, stated that both closed and open tasks can be better learned in an unpredictable environment.

The identification and evaluation of relevant environmental regulators is an integral part of task analysis for occupational therapists (Abreu, 1981; Poole, 1991; Sabari, 1991; Toglia, 1991). The therapist, in conjunction with the client, uses environmental regulators to promote the development of movement strategies for postural control through teaching, learning, and relearning of tasks and activities of daily living (ADL) (Abreu, 1992). The use of tasks in occupational therapy requires that the therapist and the client examine and analyze various activities to identify the component parameters that are appropriate for use in evaluation and treatment (Abreu & Toglia, 1987; Mosey, 1981). The therapist examines the environmental parameters of each task to develop the most effective learning context so that the client can generalize motor learning from treatment tasks to functional activities like dressing and bathing. The client examines the task to see whether it is meaningful.

Persons who have had stroke, one of the largest populations seen by occupational therapists, may show a decreased ability to perceive environmental regulators and to develop effective movement strategies for postural control. They also may exhibit sensory, cognitive-perceptual, and motor dysfunction, which can inhibit postural adjustment and interfere with ADL such as dressing, cooking, walking, or driving.

When compared to persons who have had stroke, persons with hemiplegia were found to show a significant reduction in anticipatory and adaptive postural adjustments (Horak, Esselman, Anderson, & Lynch, 1984; Mizrahi, Solzi, Ring, & Nisell, 1989) and showed longer and more varied postural responses, a lack of symmetry, slower speed, and a smaller base of support that shifted to the nonparetic side (Badke & Duncan, 1983; Dettman, Linder, & Sepic, 1987; DiFabio & Badke, 1990a, 1990b; Rosencrance & Giuliani, 1991).

One of the therapeutic goals after stroke is for the person to relearn postural control through the use of tasks and activities. Nashner's studies (1976, 1985) on the effect of environmental regulators on postural control used tasks and activities while subjects were standing. Other studies of tasks performed while subjects were standing showed that different postural strategies were used to cope with a variety of predictable and unpredictable mechanical and sensory perturbations (Horak & Nashner, 1986; Lee, 1980; Nashner, Woollacott & Tuma, 1979; Winter, Patla, & Frank, 1990). These findings support the idea that postural stability is greater when responding to predictable as opposed to unpredictable disturbances.

Most tasks and ADL require a reaching movement that creates a postural perturbation or imbalance. In response, the person must develop a postural control strategy to compensate for the effect of the perturbation or risk falling or jeopardizing physical safety. Furthermore, the person must maintain this balance while reaching under a variety of environmental conditions. Many of the tasks and ADL that require reaching are performed while in a seated position, especially by persons who cannot stand independently. Although we have knowledge of studies of postural control in reaching from a standing position, no studies have been conducted of persons who have had stroke reaching from a seated position. Such information can assist the therapist in identifying the most appropriate environment for postural training. Therefore, the purpose of this study was to examine the effect of environmental predictability on postural control after stroke.

Trajectory (the pathway followed by the subject's body center of pressure with respect to time during the reaching task) was used to formulate an index of postural control. The body center of pressure is the shift of the center of mass of the seated subject over a supporting surface.

For this study, the trajectory of a reaching task was measured by having each subject touch a target board. An instability ratio was obtained as the quotient of two mathematical expressions: the value of a direct straight line over the value of the subject's actual trajectory. Measurement was over time and operationally defined as two ratios: trajectory instability in the anterior-posterior plane and trajectory instability in the medial-lateral plane. The results were reported as a ratio of instability; the higher the ratio, the less stable the trajectory. The four hypotheses tested were:

1. Trajectory stability will be greater when responding to the predictable reaching task than to the unpredictable reaching task.
2. Trajectory stability will be greater for the control subjects than for the subjects who had stroke for both the predictable and the unpredictable reaching activities.
3. Trajectory stability will change with the direction of the reaching task.
4. An interaction will exist among trajectory stability, predictability, group classification, and direction.

Method

Subjects

Subjects for the study were selected from a pool of volunteers recruited through the rehabilitation and hospital volunteer departments at Helen Hayes Hospital, West Haverstraw, New York. The sample was composed of 100 persons, 50 who had not had stroke (control group) and 50 with poststroke hemiplegia. The two groups were matched by age and gender. The ages of the subjects ranged from 40 years to 85 years ($M = 64$, $SD = 12$). There were 25 women and 25 men in each group; 94 subjects were right-handed and 6 were left-handed. Of the left-handed subjects, four were healthy, one had right hemiplegia, and one had left hemiplegia. The weight of the subjects ranged from 101 lb to 270 lb ($M = 164.80$, $SD = 33.60$). Height ranged from 58 inches to 75 inches ($M = 64.45$, $SD = 3.69$). The control subjects had no history of central nervous system disease. The subjects with hemiplegia were equally divided: 25 had a right-side unilateral lesion and 25 had a left-side unilateral lesion. The range of time from onset of stoke to testing was 1 to 12 months ($M = 3.48$, $SD = 3.57$). The subjects with hemiplegia met the following criteria: they sustained a unilateral brain lesion, were able to comprehend and follow three-step instructions, and were able to maintain sitting balance independently.

Instrumentation

An electromechanical system (see Figure 1) was designed to measure the trajectory stability of the body center of pressure. The system was composed of a standard wheelchair placed on four force plate transducers, a target board, and an IBM personal computer[1] The supporting plane of the wheelchair seat was monitored by the four force plate transducers to determine the body center of pressure of the subject–wheelchair arrangement independent of the body weight of the subject and the weight of the wheelchair The transducers produced an output voltage that was directionally proportional to the force applied and was dependent on the position of the body center of pressure. The voltage signals from the four transducers were converted by an analog-digital system into digital values. The digital values were processed by programs designed for the computer to measure the body center of pressure.

The transducers consisted of strain gauges attached to a central plate supported by two cantilever beams. This design gave an output that was independent of the wheelchair and constant over the surface of the plate. Reports on the validity of the transducers by Wheatley (1982) show the calibration characteristics are highly linear at .99 and have a sensitivity variation for tracking movement as small as 1 mm. The electromechanical system was also tested at the Center for Rehabilitation Technology at Helen Hayes Hospital and was found to be accurate to 2% of the full scale operating load.

The electromechanical system's target board was 2 ft

[1]Manufactured by International Business Machines Corporation, Armonk, NY 10504.

Figure 1. The electromechanical system.

× 3 ft, with two target lights. The board was constructed of clear plastic and was adjustable so as to allow for standardized placement. The board was controlled by two software programs specifically written for this study to light the targets under predictable and unpredictable conditions. The predictable conditions were fixed in speed, interval of presentation, and direction. Under the predictable conditions, the right and left target lights were activated 10 times at equal intervals, first on one side and then on the other. The targets always remained on the side where they started. The unpredictable conditions were programmed to be random, lighting the target lights with variable speed, intervals of presentation, and direction. The targets were presented randomly on the right or left side. The programs also initiated a standard auditory (bell) cue to signal the beginning of the test. The target board was also connected to the analog-digital system and interfaced with the computer so as to coordinate both the initiation of the targets and the compilation and analysis of the resulting data.

Design

A repeated-measures research design was used to examine the influence of three independent variables. The three independent variables were (a) predictability (predictable vs. unpredictable), (b) group classification (control group vs. group with hemiplegia), and (c) direction of activity (right vs. left). The dependent variable was postural control as measured by the trajectory of the body center of pressure in both the anterior-posterior and medial-lateral planes.

Procedure

Each of the subjects was seated in the standard wheelchair used in the electromechanical system. The target board was then placed in front of the subject at a distance of 1¼ arm's length. The arm length was measured from the acromion of the shoulder joint to the base of the thumb while the subject clasped both hands together in an extended position that allowed the subject with hemiplegia to move in either direction regardless of the impaired side. After individual measurements and adjustments, each subject was asked to reach and touch the target light when it was lighted, with both hands clasped together. Each subject was tested for a maximum period of 90 sec.

The scores for the dependent variable, trajectory stability, were obtained from the electromechanical system through a third computer program written for this study. For descriptive purposes, the scores were reported as the mean trajectory instability ratios and plotted for each combination of independent variable levels (predictable vs. unpredictable × without hemiplegia vs. with hemiplegia × right vs. left) within both the anterior-posterior and medial-lateral planes.

Data Analysis

To test the effects on trajectory stability of stimulus predictability (predictable vs. unpredictable), group classification (without hemiplegia vs. with hemiplegia) and direction (right vs. left), and all resulting potential interactions, split-plot 2 × 2 × 2 analyses of variance (ANOVAs) were conducted separately for the anterior-posterior and medial-lateral planes. In conducting these analyses, all hypothesis tests were two-tailed and were conducted at the .05 alpha level. The dependent variable consisted of the average trajectory instability score across experimental trials; within each of the four plane × direction conditions the 10 subtrial scores were averaged for the predictable condition and the five subtrial scores were averaged for the unpredictable condition. The Statistical Package for the Social Sciences-X (SPSS-X), third edition (SPSS, 1988) was used for all statistical analyses.

Results

The plot of the trajectory instability ratio means for each of the eight (2 × 2 × 2) conditions within the anterior-posterior and medial-lateral planes is shown in Figure 2. The results plot the degree of instability—the higher the ratio, the less stable the trajectory— in the two planes for group, predictability, and direction conditions. Tables 1 and 2 provide the corresponding 2 × 2 × 2 ANOVA results.

Table 1
Results of Analysis of Variance of Trajectory Instability Ratios Scores for Anterior-Posterior Plane

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F	Significance of F
Group	1.71	1	1.71	19.82	<.0005
Error	8.44	98	.09		
Predictability	50	1	50	12.95	<.001
Group × predictability	.64	1	.64	16.79	< 0005
Error	3.75	98	.04		
Direction	.43	1	.43	13.73	<.0005
Group × direction	.49	1	49	15.68	<.0005
Error	3.08	98	.03		
Predictability × direction	.68	1	.68	24.60	<.0005
Predictability × group × direction	77	1	77	27.84	<.0005
Error	2.71	98	.03		

For the anterior-posterior plane, each of the three main effects, each of the three two-way interactions, and the three-way interaction were all significant beyond the .001 level. For the medial-lateral plane, only the group main effect, the predictability main effect, and the predictability × group interaction were significant ($p < .0005$).

Discussion

The findings of this study did not support the first hypothesis that trajectory stability is greater when re-

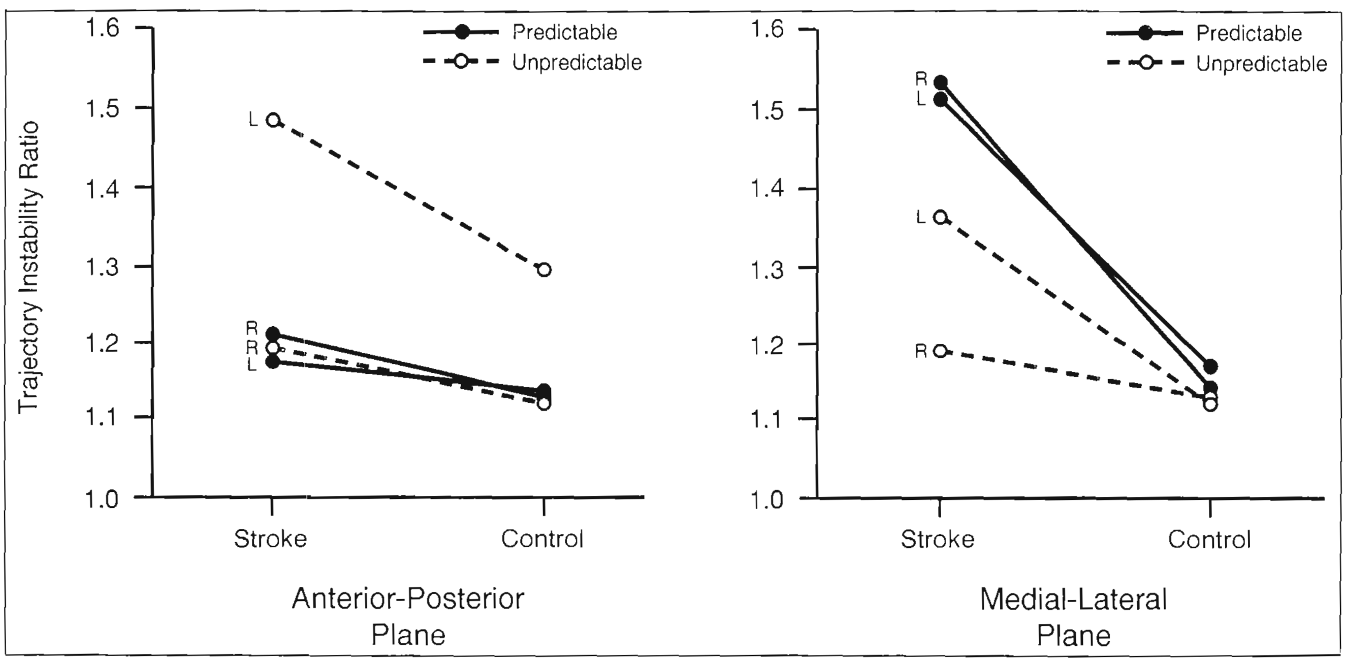


Figure 2. Mean trajectory instability ratios for group × predictability × direction conditions within anterior-posterior and medial-lateral planes.

Table 2
Results of Analysis of Variance of Trajectory Instability Ratios Scores for Medial-Lateral Plane

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F	Significance of F
Group	6.52	1	6.52	29.25	<.0005
Error	21.85	98	.22		
Predictability	1.88	1	1.88	22.06	<.0005
Group × predictability	1.31	1	1.31	15.33	<.0005
Error	8.37	98	.09		
Direction	.17	1	17	1.30	.258
Group × direction	10	1	10	76	.385
Error	13.13	98	.13		
Predictability × direction	.18	1	18	2.63	108
Predictability × group × direction	.32	1	.32	4.74	<.032
Error	6.52	98	.07		

sponding to the predictable reaching task than to the unpredictable reaching task. Although the effect of predictability was significant, the results were not as hypothesized. The predictable reaching task resulted in a higher degree of instability than the unpredictable task when reaching to the right, as measured in the anterior-posterior plane and when reaching in either direction as measured in the medial-lateral plane for all subjects (see Tables 3 and 4). One possibility for this finding may be that the unpredictable task demands a greater cognitive effort, which in turn facilitates the formulation of a more effective movement strategy for postural stability.

The results did support the second hypothesis, that trajectory stability was greater for the control group as compared to the group with hemiplegia for both the predictable and unpredictable reaching tasks. In fact, there was a higher degree of instability with more variation in the group with hemiplegia than in the control group, a finding consistent with previously cited studies (Badke & Duncan, 1983; Horak et al., 1984).

Because trajectory stability changed with the direction of the reaching task, but only in the anterior-posterior plane and not in the medial-lateral plane in all subjects, the third hypothesis was not supported. In this study, body displacement between the two planes was variable and may have contributed to the differences in trajectory stability. Postural studies have found that, during perturbations, subjects with hemiplegia show a higher body displacement in the anterior-posterior plane than in the medial-lateral plane (Mizrahi et al., 1989).

The finding of a relationship among predictability, group classification, direction, and trajectory stability supports the fourth hypothesis. This statistically significant three-way interaction appears largely due to the different patterns of performance of the subjects with hemiplegia across predictability and direction. Figure 3 is an example of the performance of one control subject and one subject with hemiplegia completing two reaching tasks. The plot of the reaching task for the subject with hemiplegia shows a very varied pattern of performance, whereas the plot of the control subject shows a strikingly similar pattern of performance. Persons who have had stroke have the attentional ability to initiate effective motor strategies in unpredictable environments. This ability is influenced by the degree of unpredictability. In this study, the degree of environmental unpredictability may not have been high enough to elicit a difference between the predictable reaching task and the unpredictable reaching task for the control subjects. The three-way interaction appears largely due to these different patterns of performance. In addition, the difference in the three-way interactions in the anterior-posterior and medial-lateral planes may be due to an artifact of the electromechanical system.

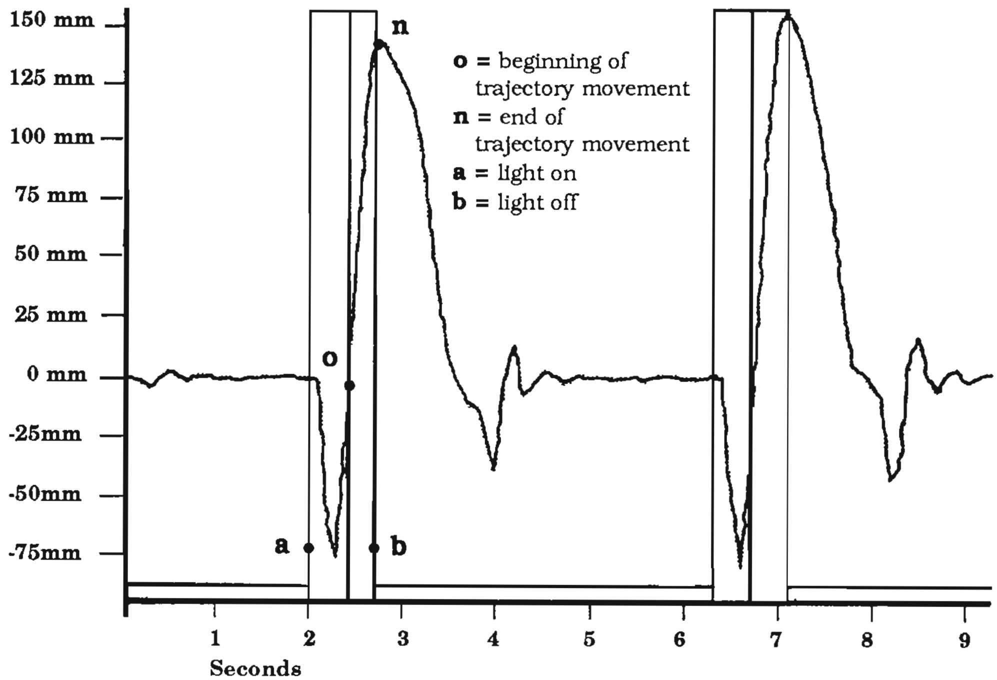
The possibility of dysfunctional postural laterality in the stroke group may have contributed to the difference found in trajectory instability when the reaching activity was to the left. Because 48 out of 50 subjects with hemiplegia were right-handed, it is plausible that their postural control was less adaptable when the reaching task was to the left. Although research on postural laterality is lacking, Kohen-Raz (1986) suggested that some children

Table 3
Means and Standard Deviations of Trajectory Instability Ratios: Anterior-Posterior Plane

Group	Predictable Right		Unpredictable Right		Predictable Left		Unpredictable Left	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Stroke ($n = 50$)	1.212	.159	1.192	176	1.178	.122	1.498	.522
Control ($n = 50$)	1.144	.076	1.139	.065	1.145	103	1.130	.052
Total ($N = 100$)	1.178	.129	1.166	.135	1.161	.113	1.314	.413

Table 4
Means and Standard Deviations of Trajectory Instability Ratios: Medial-Lateral Plane

Group	Predictable Right		Unpredictable Right		Predictable Left		Unpredictable Left	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Stroke ($n = 50$)	1.543	568	1.194	151	1.519	703	1.365	.379
Control ($n = 50$)	1.149	.082	1.141	.093	1.173	118	1.136	.063
Total ($N = 100$)	1.346	.450	1.167	128	1.346	.531	1.251	.294



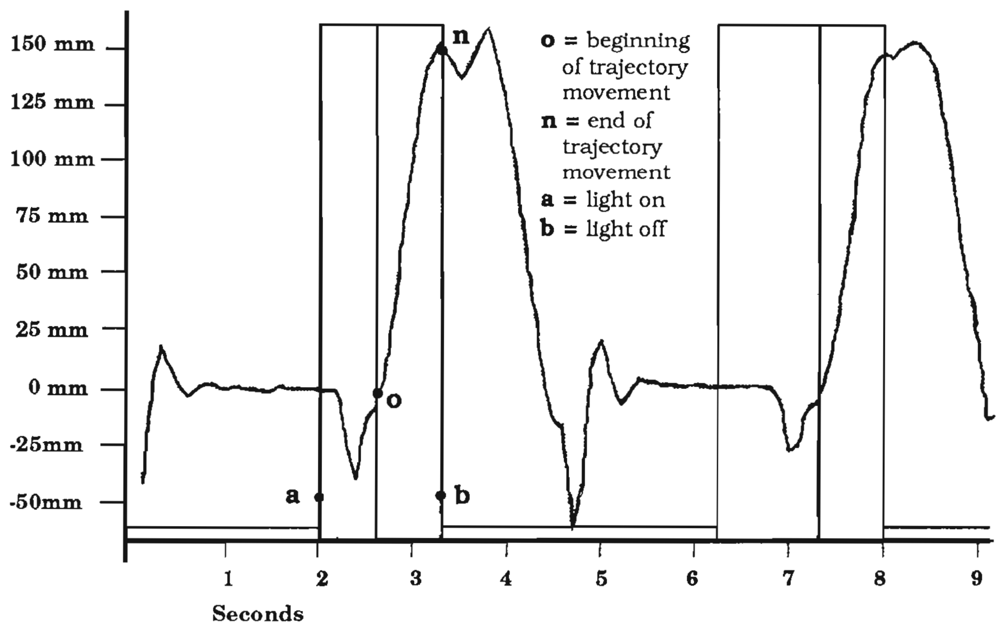


Figure 3. Sample of two reaching cycles as measured in the anterior-posterior planes. Top figure shows predictable activity to the left for control subject; bottom figure shows predictable activity to the left for subject with hemiplegia.

with brain injury tend to show greater stability to the left side.

Implications

Occupational therapists have traditionally believed in the use of a hierarchical approach for the evaluation and treatment of postural control in clients with brain injury. Therapists believe that the tasks and activities used should go from simple to complex, starting in a predictable environment and proceeding to an unpredictable environment (Abreu & Toglia, 1987). This stage-specific approach creates a spectrum of increasing processing demands. The assumption underlying this approach is that clients will be more successful in maintaining postural control while accomplishing tasks done in predictable as opposed to unpredictable conditions. The predictable environmental condition is presumed to be easier than the unpredictable one. The findings of this study show that higher processing demands required with some unpredictable conditions helped the subjects with hemiplegia to develop a more effective cognitive-perceptual and motor strategy, resulting in a more stable postural control. That is, the unpredictable conditions elicited better postural control than the predictable ones. Perhaps the two conditions, predictable and unpredictable, should be treated concurrently, rather than sequentially, and in a multivaried environment.

Unpredictable conditions represent environmental variability, which, according to Schmidt (1988), elicits a greater level of anticipatory awareness and readiness for a person than a predictable condition. Perturbations cause postural adjustments, which are known to be modified by the subject's anticipatory awareness and readiness regarding the expectation of a stimulus change (Horak, Diener, & Nashner, 1989). This increased state of anticipatory awareness and readiness, or central-set, prepares the person's sensory and motor systems for the anticipated task conditions. Schmidt (1988) proposed that variable (unpredictable) conditions are, therefore, better for the learning of motor skills than predictable conditions for both open and closed skills. This study tends to support his position.

Several limitations should be considered when evaluating the results of this study First, the sample was composed of volunteer subjects recruited specifically for this study. A convenience sample may not be representative. Second, the electromechanical system may have produced an artifact that may explain the difference in results in the anterior-posterior plane and the medial-lateral plane. Third, the unpredictable environmental condition may have been too constrained. For the purpose of this study, *predictability* was defined to include speed, interval of presentation, and direction; consequently, generalization to other unpredictable conditions may not be possible. Finally, the design of the study might have created a confounding problem with the order of activity presentation, but counterbalancing was used in an attempt to control this effect.

Further research to address these limitations may include replication of this study with random sampling, investigation of the differences between the findings of the anterior-posterior and the medial-lateral planes, and continued studies using different degrees of predictability.

The implications of this study for occupational therapists support the need for further research on the spatial and temporal effects of environmental regulators on postural control and may serve to increase the therapists' understanding of the teaching and learning of postural control strategies. Furthermore, the electromechanical system used in this study to measure trajectory stability with seated subjects may be beneficial for studying clients in wheelchairs to compare generalization of postural control training under different environmental conditions, including predictable and unpredictable. The electromechanical system may also be valuable for the postural analysis of other persons with neurological impairments.

This study should be replicated and expanded to confirm the validity of the findings and to determine the underlying mechanism of processing environmental regulators. Such studies may expand motor control theories. ▲

Acknowledgments

I thank Martin Ferguson-Pell, PhD. for sponsoring, mentoring, and assisting with this project; Mike Carlson, PhD. for his statistical advice; and staff members of the Rehabilitation Technology, Occupational Therapy, and Audio Visual departments at Helen Hayes Hospital.

This study was conducted under the auspices of the Center of Rehabilitation Technology at Helen Hayes Hospital. This article was based on a dissertation at New York University guided by Martin Ferguson-Pell, PhD. Deborah Labovitz, PhD. Arthur J. Nelson, PhD. Sharon I. Weinberg, PhD. Mark Malagodi, PhD. and Wen K. Ling, PhD.

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