The Effects of Dynavision Rehabilitation on Behind-the-Wheel Driving Ability and Selected Psychomotor Abilities of Persons After Stroke

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Objective. *Many conventional rehabilitation exercises, such as pencil-and-paper and computer tasks, may not train perceptual and motor skills as applied to a complex, multiskill activity such as driving. The present study examined the usefulness of the Dynavision apparatus for driving-related rehabilitation. The Dynavision was designed to train visual scanning, peripheral visual awareness, visual attention, and visual-motor reaction time across a broad, active visual field.*

Method. *Ten persons with a cerebrovascular accident participated in the study. All had failed behind-the-wheel driving assessments. Subjects participated in a 6-week Dynavision training program using exercises designed to impose various motor, perceptual, and cognitive demands.*

Results. *Dynavision training resulted in significantly improved behind-the-wheel driving assessments as compared to expected outcomes. Comparisons between pretests, posttests, and follow-up tests on a number of Dynavision, response, and reaction time variables showed significant improvements and maintenance effects. Dynavision performance, and, to a lesser extent, choice visual reaction and response times, were found to differentiate between persons assessed as safe and unsafe to drive, and between older and younger drivers. Subject self-reports suggested that a variety of training-related improvements had occurred in everyday functioning.*

Conclusion. *Dynavision training shows some rehabilitative promise for improving driving and basic psychomotor skills. Future research on the benefits and limitations of this apparatus should use finer laboratory skill measures and more comprehensive tests of driving and daily functioning to assess more thoroughly skill improvements in persons after stroke.*

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The motor, perceptual, cognitive, or psychological deficits that result from a cerebrovascular accident (CVA, or stroke) may vary widely as a function of the location and extent of damage. These impairments may affect a number of everyday life skills, including the ability to drive a motor vehicle. Although research has not defined a highly specific set of driving skills (Galski, Ehle, & Bruno, 1990), one researcher has described the driving task in terms of a hierarchical model involving three unique but interdependent performance levels (Michon, 1979). The top or *strategic* level involves decisions made before any driving occurs (e.g., deciding which route to take to a particular destination, deciding whether to drive on a particular day given prevailing weather conditions). The second or *tactical* level involves behavior and risk-related decision making that occurs in traffic (e.g., deciding whether to pass another car in a given situation, judging the appropriate time to turn on the headlights). The third or *operational* level involves driving-specific skills (such as using the brakes to slow down, signaling before turning) and underlying psychomotor skills, (such as visual perception, attention, visual-motor coordination, etc.) (van Zomeren, Brouwer, & Minderhoud, 1987). Although impairments at any one of the three levels may contribute to poor driving, most research has focused on impairments at the tactical level and, in particular, at the operational level, possibly because these areas are most directly related to driving defined as a *learned skill.*

Bardach (1971) stressed that the most significant impairments in driving appeared in persons with perceptual and cognitive problems rather than motor or emotional problems. Most of these persons had damage to the right cerebral hemisphere. This finding is not unusual, given that certain forms of perceptual and cognitive impairment—in particular attentional and visual skills deficits—are common to right hemisphere damage (e.g., Gianutsos & Matheson, 1987; Warren, 1990, 1993) due to the differential specificity of the two hemispheres. Specifically, the subjects observed by Bardach exhibited problems in scanning the environment, poor planning, an inability to shift according to the changing demands of the driving task, distractibility, poor judgment, confusion, reduced awareness, or reduced peripheral visual awareness.

Other research has confirmed or extended many of Bardach's original observations, in particular those related to effects of impaired visual-perceptual and visual-cognitive skills (e.g., Galski, Bruno, & Ehle, 1992; Nouri & Lincoln, 1992; Shore, Gurgold, & Robbins, 1980; Sivak, Olson, Kewman, Won, & Henson, 1981; Quigley & DeLisa, 1983). In an extensive summary of the literature on brain damage and driving, van Zomeren et al. (1987) concluded that research findings on skill deficits at Michon's (1979) operational (or basic) level of driving generally fall into five categories: (a) inadequate scanning of the environment, (b) problems in spatial perception and orientation, (c) poor visual tracking, (d) slowness in acting, and (e) confusion when complex actions or sequences of actions are to be carried out.

Few reliable rehabilitation methods have been devised to target driving-related deficits. Although the current approach to improving such skills usually involves in-car driver retraining lessons (Cumbo-Misheck, 1993; Quigley & DeLisa, 1983; van Zomeren et al., 1987), an alternative or supplementary approach would involve rehabilitating the underlying skills that support performance on the driving task (van Zomeren et al., 1987). Alternative approaches include conventional perceptual-cognitive rehabilitation techniques, such as pencil-and-paper or computer tasks, puzzles, and related activities. At least one major rehabilitation center encourages clients to use such methods for perceptual-cognitive improvement (M. Young, personal communication, 1993), and one study has also successfully used them to improve the driving performance of persons with stroke-related injuries and other head injuries (Sivak et al., 1984).

For use in driving rehabilitation, however, conventional techniques are arguably limited in several respects. The training environment often consists of only a standard sized sheet of paper or computer monitor (i.e., 21 cm × 28 cm). The driving environment, however, encompasses a far broader field, in which eye scanning and visual attention must occur over a greater range of space, often involving head movement. Driving also imposes a high demand on ambient (peripheral) vision, which affords a viewer with a general awareness of the surroundings (Warren, 1990).

Another limitation of conventional tasks is that they are often more useful for improving specific skills (such as reading) rather than the basic abilities that may underlie these skills (Warren, 1993). Finally, many standard tasks do not sufficiently emphasize multiskill or multisensorial task performance. That is, they often fail to involve and coordinate visual, auditory, tactile, and cognitive capacities in the performance of a single task—something that is a defining feature of the driving experience.

The purpose of the present study was to explore the usefulness of the Dynavision[1] apparatus for improving the performance of persons with stroke on several measures of psychomotor ability (e.g., response time, anticipation time) and on a behind-the-wheel (BTW) driving test. The Dynavision apparatus is designed to train visual scanning, peripheral visual awareness, visual attention, and visual-motor reaction time across a broad, active visual field. It also includes features that require trainees to execute complex visual-motor response sequences, to use basic cognitive skills (e. g., short-term memory), and to show physical and mental endurance. As such, this apparatus may address some of the deficits targeted by conventional methods, but may do so with a wider, more active visual training environment, and by placing higher demands on integrated visual-motor and visual-cognitive functions.

Method

Subjects

Ten subjects were recruited from the Hugh Macmillan Rehabilitation Centre (HMRC) in Toronto. All met the following criteria: (a) had stroke at least 6 and not more than 18 months before the study, (b) had marked visual and attentional difficulties while driving, as assessed by driving specialists at the Centre, (c) were at least 45 years and not more than 80 years of age, and (d) had already been judged unsafe to drive in one BTW driving assessment (conducted by specialists at the Centre) (see Table 1). Stroke-related deficits included hemiparesis and hemiplegia, moderate to mild hemi-inattention, and mild visual field loss, although the distribution and severity

[1]Manufactured by Performance Enterprises, 76 Major Button's Drive, Markham, Ontario, Canada L3P 3G7

Table 1
Subject Characteristics

Subject	Age (Years)	Gender	Etiology	Months Since Stroke
1	51	M	RCVA	–
2	66	M	LCVA	12
3	46	M	RCVA	12
4	69	F	RCVA	14
5	64	M	LCVA	17
6	65	F	RCVA	9
7	73	M	NC	6
8	58	M	LCVA	9
9	72	M	NC	6
10	67	M	LCVA	6

Note: RCVA = right cerebrovascular accident, LCVA = left cerebrovascular accident
NC = not classified as RCVA or LCVA.

of these impairments were not particular to specific diagnoses. Subjects did not show marked impairment in specific cognitive functions (e.g., memory or speech impairment)

Apparatus

Four measures were used to collect data on the following nine psychomotor variables:

1. Dynavision endurance score (number of hits)
2. Dynavision speed score (number of hits)
3. Simple response time (millisec)
4. Simple visual reaction time (millisec)
5. Simple movement time (millisec)
6. Choice response time (millisec)
7. Choice visual reaction time (millisec)
8. Choice movement time (millisec)
9. Anticipation time (millisec)
10. Behind-the-Wheel driving outcome (safe or unsafe to drive).

Dynavision. The Dynavision apparatus was used for rehabilitation and for testing visual-motor response speed to light stimuli in focal and peripheral visual fields. The Dynavision consists of a wall-mounted board (120 cm × 120 cm) housing 64 small square buttons arranged in a pattern of five nested rings. The apparatus can generate a number of training or testing tasks, which may be characterized as either *apparatus-paced* or *self-paced.* In apparatus-paced exercises, random buttons illuminate one at a time and remain lit for a preset time period (.1, .25, .4, .5, .75, or 1.0 sec) before extinguishing and reappearing at new locations. A user, standing before the apparatus, must strike each of these illuminated target buttons before it extinguishes. The self-paced tasks are identical to the apparatus-paced tasks except that targets do not change location *until* struck. In either type of task, users may be required to locate target buttons in one of two ways, depending on their rehabilitative needs. To emphasize peripheral visual attention, a user is instructed to fix his eyes directly forward and use peripheral vision to see illuminated buttons. To emphasize scanning, a user is instructed to find the targets by visually searching the board (shifting the eyes and head). In both types of tasks, a beep signals a successful hit, and the total number of hits is recorded by the apparatus. More hits reflect faster visual-motor responses, and thus better performance.

Other tasks may involve visually tracking target buttons, rather than striking them. For all tasks, the duration of target light illumination, the duration of the task, the quadrants (or sections), and the size of the board used in training may all be modified to target the ability level or impairment of the user In addition, a small liquid crystal display (LCD) near the center of the board can be set to display up to seven computer-selected digits for brief, preset exposure periods (.01, .05, .1, .25, .4, .5, .75, or 1.0 sec) at 5-sec intervals. Users can be instructed to call out or manipulate digits (e.g., add or multiply) during a button-striking task, thereby increasing the complexity of the task. This requirement also ensures that users' eyes are fixed forward toward the center of the board. Users may be seated or standing as they perform tasks (see Figure 1). Tasks are usually performed in dim lighting conditions to ensure the visibility of illuminated buttons. In the present study, ambient light levels varied narrowly, between .14 and .62 cd/m^2, according to the particular preferences of each subject. A reliability study has found that several Dynavision tasks have moderate test–retest reliability (Klavora, Gaskovski, & Forsyth, in press).

The Dynavision exercises used for testing in this study were an endurance task (a 240 second, self-paced button-striking task) and a speed task (a 60 sec, apparatus-paced button striking task, in which a target button illuminates for 1 sec only before it extinguishes and a new button illuminates) The dependent variable for both tasks was number of hits.

Also recorded for the speed task were the number of hits on the inner board (the inner three rings of the board), which imposes demands on focal visual ability,

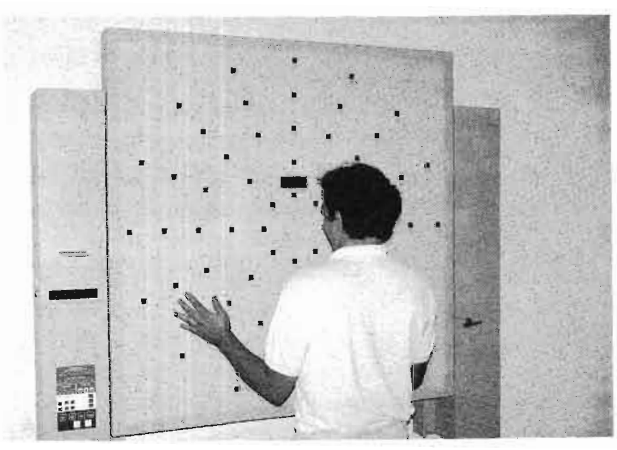

Figure 1. A standing user of the Dynavision apparatus.

and the number of hits on the outer board (the outer two rings of the board), which imposes demands on peripheral visual ability.

Simple and choice response timers. These devices measure the speed at which a subject can respond to a light stimulus by pressing a button. The simple response time device consists of a starting key and a target key. A subject is instructed to press and hold down the starting key with one hand, at which time a "ready" light illuminates, signaling that the test has begun. Following a brief interval, whose duration varies randomly between 1, 2, or 3 sec, another light stimulus situated immediately behind the target key illuminates; at this time the target key must be struck as quickly as possible with the same hand that held down the starting key. The choice response timer is similar to the simple response timer, except that it has four target keys with four corresponding light stimuli. In both tasks the distance between the starting and target keys is 30 cm. In the choice task, the four target keys are separated by 15 cm. The starting and target keys are 2 cm × 2 cm. In both tasks, the responding hand moves forward toward the target key.

The dependent variables for both tasks are visual reaction (VR) time (time to raise hand off of the starting key upon the onset of the stimulus), movement (M) time (time to move the responding hand to the target key, *after* it has been raised off of the starting key), and response time (the time it takes to complete the entire response, that is, the sum of visual reaction and movement times). All reported times are based on averages for both hands. Lower times indicate faster response capacities.

Bassin Anticipation Timer. This apparatus measures the accuracy with which a subject can anticipate the arrival of a moving light stimulus at a target point. The apparatus consists of a track (approximately 2.5 m long) with a row of 49 small lights set along its length. During the task, the subject is positioned at one end of the track with one finger on a response button. The lights along the track briefly illuminate in successive order (starting at the end of the track opposite the subject), generating the illusion of one light travelling down the track. The subject is instructed to watch the oncoming light and anticipate its arrival at the last bulb on the track by pressing the response button. The speed of the light is preset at 1, 5, 10, 15, or 20 miles per hour, and randomly varies from trial to trial. The dependent variable is anticipation time (time to respond to the arrival of the light at the target). Lower times reflect more accurate anticipation capacities.

Behind-the-Wheel (BTW) driving assessment. The BTW driving assessment was a subjective on-road evaluation of driving skills. The assessment was conducted at the HMRC by trained, experienced driving specialists. The assessment takes 45 min to 60 min and requires clients to navigate through various traffic settings ranging from residential areas to busier main roads. Assessors instruct clients to perform a number of basic maneuvers, including stops, turns, and so on. Clients are subjectively assessed on 24 different aspects of their driving performance, such as steering, braking, lane changes, perception, and attitude. This information is used to generate a subjective, global evaluation of the client's level of driving competence and fitness. Specifically, clients are assessed as either "safe to resume driving and/or to receive driving lessons" or "unsafe to resume driving at this time."

Procedure

The study involved a pretest, treatment, posttest, and follow-up test. Subjects initially participated in an orientation session in which the nature of the study and its implications were outlined. A few days after the orientation session, consenting subjects participated in a familiarization session in which they were given an opportunity to learn how to perform tasks on the various apparatus (e.g., how to respond to stimuli properly). Approximately 2 days after the familiarization session, subjects were pretested on the simple and choice response timers, the anticipation timer, and on the Dynavision apparatus.

After pretesting, the subjects participated in a 6-week training program on the Dynavision, with three sessions per week and approximately 20 min of total training time per session (sessions lasted about 45 min with occasional breaks). All subjects received the same training program, with minor modifications to accommodate the expected variation in performance abilities for different persons. The Dynavision training tasks imposed demands on a variety of skills and abilities, including visual-motor coordination and response time, peripheral awareness, visual attention, eye scanning, concentration, simple cognitive processing, physical endurance, and combinations of these skills. The training program was designed so that in each new training week, subjects trained on tasks that were more challenging versions of exercises used in the previous week.

At the conclusion of the training program, subjects were posttested on all dependent variables, including a second BTW driving assessment. Three months after the posttest, 6 of 10 subjects participated in a follow-up test on the Dynavision endurance and speed tasks, the simple and choice response timer, and the anticipation timer.

Results

On their second BTW driving assessment, 6 out of the 10 subjects earned a rating of "safe to resume driving and/or to receive on-road driving lessons," and 4 subjects were assessed as "unsafe to drive at this time." The expected frequency for safe assessments on a second attempt among typical HMRC clients during the period of the study was 24%; the safe rate for study subjects was 60%. A chi-square test showed a significant difference between

Table 2
Performance of Subjects on Nine Psychomotor Variables

Variable	*M (SD)* Pretest (*N* = 10)	Posttest (*N* = 10)	Follow-up (*n* = 6)	Pretest/Posttest *t*
Dynavision Endurance Score (hits)	191.7 (46.56)	257.6 (62.12)	245.3 (43.46)	6.97**
Dynavision Speed Score (hits)	21.3 (9.14)	56.3 (19.17)	53.2 (15.66)	9.12**
Simple Response Time (msec)	751 (110)	601 (90)	615 (70)	5.03**
Simple Visual Reaction Time (msec)	433 (49)	351 (41)	351 (43)	4.08*
Simple Movement Time (msec)	317 (92)	264 (61)	263 (61)	3.45**
Choice Response Time (msec)	797 (80)	685 (70)	710 (80)	4.63*
Choice Visual Reaction Time (msec)	462 (23)	422 (51)	444 (47)	2.15
Choice Movement Time (msec)	335 (73)	263 (58)	266 (68)	6.18**
Anticipation Time (msec)	219 (268)	132 (64)	135 (67)	1.7

Note. T tests are two-tailed.
$^*p \leq .01$ $^{**}p \leq .001$.

the observed and expected safe rate frequencies (χ^2 [df = 1] = 4.47, p < .05). The expected frequency was based on the driving assessment outcomes of 33 HMRC clients who were highly similar to the study sample with respect to mean age, gender proportion, and CVA etiology. It should be noted, however, that for the HMRC group, the designation of unsafe was applied not only to those persons who were assessed as such on a second BTW evaluation, but also to those who did not return for a second evaluation. The BTW results in this study, therefore, may be considered somewhat optimistic, because the assumption is being made that those clients who did not return for a second evaluation would have likely been assessed as unsafe if they did return.

On the second BTW driving assessment, all five subjects 65 years of age or younger were assessed as safe drivers, whereas only 1 of 5 subjects older than 65 years of age was assessed as a safe driver. A chi-square test (with a Yates correction for continuity) indicated that the outcomes between the two age groups were significantly different (χ^2 [df = 1] = 4.10, p < .05).

Table 2 shows descriptive data and t-test analyses for psychomotor data. Between the pretests and posttests, significant improvements (at p < .01 and p < .001 levels of probability) were found on all dependent variables, except for choice visual reaction time and anticipation time.

For the six subjects who participated in the follow-up, analyses of variance over the three test conditions showed significant F-values for all (laboratory) dependent variables, except for choice visual reaction time and anticipation time. None of the paired t tests for post- and follow-up tests was significant, suggesting training maintenance effects for all variables (except for choice visual reaction and anticipation time, which showed no training-related improvement between the pretest and posttest).

Table 3 shows the data and analyses for the number of hits scored in the inner and outer regions of the Dynavision board on the speed task. The differences between the pretest and posttest performances were significant, increasing from 13.8 to 34.7 hits for the inner board and from 7.5 to 21.6 hits for the outer board. The proportion of hits scored in each of the two regions, however, changed only slightly on the posttest; the proportion on the outer board increased by 4.6%, whereas the proportion on the inner board decreased by 3.3%.

Analyses of variance (2 × 2) were used to compare performance differences on the psychomotor variables between distinct subject groups. The first analysis examined differences between subjects who were assessed as safe (n = 6) and unsafe to drive (n = 4) on their second BTW driving assessment, across the pretests and posttests. The analysis showed significant differences on the Dynavision endurance and speed task (F = 17.99, p < .001 and F = 16.65, p < .001, respectively) and choice visual reaction time (F = 6.02, p < .03). It was also found that posttest scores were significantly higher than pretest scores for both safe and unsafe drivers. However, the six safe drivers showed significantly higher Dynavision scores than unsafe drivers in both test conditions. An analysis of pretest differences found that safe drivers scored a significantly greater number of hits than unsafe drivers on the Dynavision endurance task [222.2 (32.23) vs. 146.0 (11.43), t (df = 8) = 5.31, $p \leq$ .001] and speed task [25.5 (9.77) vs. 15.0 (1.83), t (df = 8) = 2.57, p < .05].

A posttest analysis (see Table 4) showed that safe

Table 3
A Comparison of Inner and Outer Board Performance on Speed Task for 10 Subjects

Section of Board	Pretest *M (SD)*	Pretest %	Posttest *M (SD)*	Posttest %	*t*
Inner board (hits)	13.8 (4.05)	67.8	34.7 (7.78)	64.5	10.71**
Outer board (hits)	7.5 (5.56)	32.2	21.6 (12.38)	36.8	4.06*
Total (hits)	21.3	100.0	56.3	100.0	7.00**

$^*p \leq .01$ $^{**}p \leq .001$.

Table 4
Posttest Comparison of Safe and Unsafe Drivers on Four Psychomotor Variables

Variable	Posttest *M* (*SD*) Safe Group ($n=6$)	Unsafe Group ($n=6$)	*t*
Dynavision Endurance Score (hits)	289.0 (50.27)	210.5 (49.36)	2.45*
Dynavision Speed Score (hits)	67.7 (12.26)	39.3 (14.36)	3.25*
Choice Visual Reaction Time (msec)	394 (27)	465 (54)	2.43**
Choice Response Time (msec)	657 (66)	727 (50)	1.92**

$^*p \leq .05$ $^{**}p \leq .10$.

drivers again scored a significantly greater number of hits than unsafe drivers on both Dynavision endurance and speed task. Although there was a trend for the choice response time and choice visual reaction time to be slightly higher in the unsafe group than the safe group, these differences were not significant probably because of the small sample size.

A second analysis examined performance differences across two age categories ($<$ 65 years and $>$ 65 years); there were five subjects in each group. Significant *F* values were found for the Dynavision endurance task ($F = 13.32, p < .002$) and speed task ($F = 7.28, p < .02$). As in the safe–unsafe driver analysis reported above, younger drivers showed significantly higher Dynavision scores than older drivers in both test conditions. The pretest analysis found that younger drivers scored a significantly greater number of hits than older drivers on the Dynavision endurance task [224.0 (35.68) vs. 159.4 (31.56), t $(df = 8) = 3.03, p < .05$] and speed task [25.5 (9.77) vs. 15.0 (1.83), t $(df = 8) = 2.57, p < .05$].

In the posttest analysis (see Table 5), the younger group had a significantly higher number of hits than the older group on both Dynavision tasks, and had significantly faster choice visual reaction time. Finally, the analysis of performance differences between persons classified as left or right CVA (n = 4 for each group) showed no significant differences between the two groups on any psychomotor variables across the pretest and posttest conditions.

Discussion

Behind-the-Wheel Driving Performance

The finding that the safe rating for the study subjects was significantly greater than for the HMRC client group as a whole suggests that the Dynavision training improved driving performance. Although specific areas of performance improvement were not rigorously measured in this study, some general improvements can be inferred from a qualitative analysis of the driving evaluator's reports after the BTW assessment. Specifically, subjects whose performance was assessed as safe were observed to have shown improvements in any or all of the three following areas: (a) visual attentional capacities, including visual scanning and searching, visual attention, and spatial orientation; (b) basic cognitive functions, including anticipation, planning, and decision-making; and (c) integrated functioning, involving the capacity to exercise a number of visual and cognitive skills in busy or complex traffic settings. Some of the subjects whose performance was assessed as unsafe also showed improvements in these areas, although the improvements were relatively smaller. It is notable that the reported areas of general improvement are similar to many of the areas of functioning that have been found to be driving-relevant by other researchers (e.g., Bardach, 1971; van Zomeren et al., 1987). They also fall into Michon's operational level of driving performance (Michon, cited in van Zomeren, Brouwer, & Minderhoud, 1987). More specific effects of Dynavision training on driving ability, however, can only be inferred through an examination of subject performance on the psychomotor measures used in the study.

Psychomotor Performance

As expected, the 6 weeks of Dynavision training resulted in an increased number of hits on the Dynavision endurance and speed task. These increases most likely reflect task-specific improvements in visual-motor speed, coordination, peripheral vision, visual attention, mental endurance, as well as a good measure of upper body physical endurance. The proportional improvements on the inner and outer boards (on the speed task) between the pretest and posttest establish that the increase in number of hits was a function of increased response speed not merely to stimuli in the center of the board, but also to stimuli in the outer regions of the board, which impose greater peripheral visual demands. In fact, the proportion of outer board hits on the posttest actually increased by a small (nonsignificant) margin (4.6%), whereas the pro-

Table 5
Posttest Comparison of Younger and Older Drivers on Four Psychomotor Variables

Variable	Posttest *M (SD)* Younger Subjects[a] ($n=5$)	Older Subjects[b] ($n=5$)	*t*
Dynavision Endurance Score (hits)	295.4 (53.4)	219.8 (47.54)	2.37*
Dynavision Speed Score (hits)	69.6 (12.64)	43.0 (15.0)	3.03*
Choice Visual Reaction Time (msec)	389 (27)	456 (51)	2.60*
Choice Response Time (msec)	658 (73)	712 (55)	1.32

[a]Age$\leq$65 years.
[b]Age$>$65 years.
$^*p \leq .05$.

portion of inner board hits actually decreased (by 3.3%), suggesting that peripheral visual performance was not only constant but possibly improved between the pretest and posttest.

Significant posttest findings on the various simple and choice response variables suggest that the training generated improvements in basic psychomotor abilities. The finding that simple visual reaction time improved, however, conflicts with the widely held assumption that reaction time cannot be trained. Assuming the validity of the present finding, it is possible that the specific training undertaken in this study facilitated the likelihood that subjects could access truly maximal reaction time ranges (at least for simple stimuli). This possibility, of course, assumes that nontrained persons who have had stroke normally operate within submaximal reaction time ranges. The scope of the present study, however, neither demands nor allows for further speculation on this possibility. Future research, however, should consider with greater scrutiny the effects of training on both the simple and choice reaction times of persons after stroke.

The nonsignificant posttest versus follow-up test differences (on those variables that had otherwise improved significantly between the pretest and posttest) suggest that training effects were maintained over relatively long periods. It is also worth emphasizing that anticipation ability appeared to improve in the posttest and showed some maintenance effect, although the pretest and posttest differences were not significant.

It is possible that at least some of the general improvements reported by the driving evaluators reflect the specific improvements in simple and choice reaction, movement, and response times and Dynavision performance. Although these particular psychomotor capacities have not been identified by researchers (e.g., van Zomeren et al., 1987) as the most critical to driving, it is nonetheless likely that they underlie or operate in tandem with key abilities such as visual scanning, tracking, and responding in complex situations. Future research should attempt to clarify the function of other driving-relevant skills that improve as a result of Dynavision training.

Admittedly, the lack of a control group renders the BTW and laboratory findings tentative. Unfortunately, we found that although persons with CVA showed a high degree of motivation to participate in rehabilitation and to resume their former life-styles, few were interested in participating in a nontreatment condition, even when promised treatment at a later time. In the analysis of BTW driving assessment results, however, this problem was to some extent compensated for by the availability of expected population frequencies. With respect to the psychomotor improvements, the lack of a control group leaves open the possibility that the improvements occurred as a function of natural or spontaneous recovery. But this conclusion is unlikely. Such recovery tends to occur within 6 months of the stroke (Goldstein & Davis, 1990; Skilbeck, Wade, Hewer, & Wood, 1983), whereas subjects in the present research had had stroke 6 months to 17 months before the study. It is also worthy of note that one subject in our study who did agree to participate in the control condition showed no marked or systematic improvement in performance on the psychomotor tests or on the BTW driving assessment.

Discriminative Variables

Some psychomotor variables were found to have discriminative value. Dynavision posttest performance on both speed and endurance tasks differentiated between safe and unsafe drivers. Furthermore, it differentiated between relatively younger and older subjects, although this finding reflects the fact that almost all of the younger subjects were assessed as safe drivers and the older subjects as unsafe drivers. Pretest performance on the endurance task also differentiated between safe and unsafe drivers, even though the actual BTW driving evaluation occurred 6 weeks later. At this time, it is difficult to account fully for the discriminative power of Dynavision performance. It is possible that performance on the apparatus requires the same general visual-motor attentional and response capacities as driving, and may therefore be predictive of driving fitness (and, possibly, of performance on other complex multiskill tasks). However, the extent to which Dynavision performance makes finer distinctions (e.g., between safe, unsafe, and borderline BTW driving performance) requires further exploration.

Choice response and choice visual reaction time also appear to differentiate between subjects who were assessed as safe and unsafe on the BTW driving evaluation, although the group differences were significant at only the .10 probability level. Choice visual reaction time also differentiated between younger and older subjects, although, as noted earlier, this finding reflects the fact that most of the former were assessed as safe, and the latter as unsafe.

Other research related to the specific usefulness of response time as a discriminative variable is mixed. Sivak et al. (1981) found that two-choice response time differentiated between the driving performance of subjects with brain-damage and subjects without dysfunction. Another study found that four-choice response time differentiated BTW driving performance between borderline subjects with CVA and subjects with CVA who failed, not between borderline or fail subjects and subjects who passed (Nouri, Tinson, & Lincoln, 1987). Galski et al. (1990) reported no relationship between response time and driving, although these researchers did not specify the type of test used (i.e., simple or choice). These discrepant findings may have resulted from a variety of methodological differences, in particular the differing measures used to assess response time and driving ability. It is possible, too, that different researchers define *response time* differently. At least two of the three aforementioned studies (Nouri et al., 1987; Sivak et al., 1981) refer to response time as *reaction time,* although, strictly speaking, the latter term should be used to refer to the visual reaction time component that is obtained in most response time tests (see Apparatus section for elaboration on the differences between these terms). Galski et al. (1990) referred to reaction time but did not define it clearly. The present study was unique in that it included an analysis of not only response time, but also the separate visual and motor component times that make up response time. Ultimately, it was this finer analysis that revealed the discriminative value of choice visual reaction time (in addition to choice response), but not choice movement time.

Subjects with left and right CVA showed no performance differences on any variables, including the BTW driving outcome. As noted in the literature review, however, most driving research has found that persons with right CVA experience more significant driving-related and visual and attentional problems than persons with left CVA. The present findings serve as a reminder that it may be inappropriate to assume performance differences principally on the basis of the location of cerebral damage. In fact, many persons can often compensate for performance impairments in a number of ways, in spite of specific right or left CVA deficits (Wade, Hewer, Skilbeck, & David, 1985). For future research, it may be more appropriate to assign subjects to different experimental conditions on the basis of performance on relevant tasks, rather than on assumed differences based on diagnosis.

Self-Reports

Although statistically significant improvements on the various measures in the study may suggest the promise of the Dynavision apparatus for enhancing basic psychomotor response capacities and driving, the rehabilitative value of this or any other apparatus or technique must ultimately be assessed in terms of its effects on everyday functioning, as perceived by subjects' themselves or by persons close to the subject. After all, even highly significant findings on laboratory measures may mean little to persons with impairments unless practical, tangible benefits are discerned.

In an effort to study such potential benefits, informal interviews with subjects were conducted before, during, and after the training period. Whenever possible, corroborative information was elicited from spouses or family members. Relevant informal comments made by subjects or family at other times were also recorded. A qualitative analysis of the reports revealed that training-related improvements may have occurred in a variety of functions not assessed by the experimental tasks.

Six out of 10 subjects noted improvements in motor functioning. Subject 1 (see Table 1), who showed marked limited mobility of his left arm, was encouraged to use this arm while training (i.e., button striking). In spite of his preference for using his right arm only, by the end of the training period he was using the left more frequently and commented that he felt like he "had a left arm again." He explained that he no longer had to consciously remind himself to use his left arm in training and in many other everyday tasks, and that its use was more automatic. Subjects 4, 6, 7, 8, and 10 also reported marked improvements in impaired limb functioning, in particular in terms of increased everyday use and greater flexibility, strength, speed, motor coordination, and motor endurance. Again, these improvements were noted while subjects performed common daily activities, such as cooking or arranging items in the home.

Comments regarding perceptual or cognitive improvement were made by subjects 1, 3, 5, 7, and 10, although the statements were somewhat general. The subjects commented that they felt "sharper" and "more attentive" to their environment. The dearth of more specific reports may reflect the fact that perceptual and cognitive impairments are often not readily apparent to the persons who experience them or even to persons who interact with them (Gianutsos & Grynbaum, 1983). Notably, however, after several weeks of training, Subject 3 reported that he was becoming more aware of stimuli in his peripheral visual field, and Subject 7 stated that he believed that the training had improved his self-awareness regarding the strengths and limits of his psychomotor abilities.

Conclusion

The findings in this study are promising with respect to the usefulness of the Dynavision for improving some basic psychomotor skills, and suggestive with respect to its usefulness for improving everyday functioning. Dynavision performance and, to some extent, choice response time and visual reaction time performance appear to differentiate between relatively fit and unfit drivers. The effect of Dynavision training on the driving skills of persons after stroke is positive, at least as subjectively evaluated by driving assessors during a behind-the-wheel driving assessment. Future research with the Dynavision and similar rehabilitation apparatus should use finer and more precise dependent measures on variables, such as response time, and should also include more reliable and sophisticated measures of driving ability and everyday functioning. ▲

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